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ARMY AVIATION RDT AND E PLAN. SIXTH EDITION.(U)

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ARMY AVIATION RDT & E PLAN

OCTOBER 1977

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ARMY AVIATION RDT&E PLAN.

SIXTH EDITION.

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U.S. ARMY AVIATION
RESEARCH AND DEVELOPMENT COMMAND
ST. LOUIS, MISSOURI

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FOREWORD

The Army Aviation Research, Development, Test and Engineering (RDT&E) Plan is the U.S. Army Aviation Research and Development Command (USAAVRADCOM) response to the requirement for a Consolidated R&D Plan, which constitutes Block 13a in the Life-Cycle Management Model as described in the Joint CDC/AMC Materiel Need Procedures Handbook, March 1972. This Plan is prepared and maintained by AVRADCOM on a continuing basis to address the short- and long-range RDT&E activities directed toward achieving the Army objectives for which AVRADCOM is responsible.

This Plan presents a time-phased analysis and presentation of the scientific and technological R&D efforts required to support the development of advanced airmobile systems responsive to the future needs of the Army. Plans and objectives are set forth for Army aviation research and development activities for FY78–97, with emphasis on the period from the present to 1982. Current R&D efforts in Army air mobility are directed primarily toward the development of a family of aircraft capable of vertical and short takeoffs and landings. These aircraft will fulfill identified requirements in the land combat functions of mobility, intelligence, firepower, combat service support, and command, control, and communications.

This is the sixth issue of a document that will continue to be reviewed, revised, and augmented annually. The 1977 publication (FY78 Plan) has been printed in two volumes – a basic technical volume and an Executive Summary. The Executive Summary provides a practical, concise overview of the Plan. The classified annex was discontinued with this publication because the classified material associated with the Plan consists primarily of AAH mission profiles, airmobile system threats, and IOC dates. Although that classified material is required in the formulation of the various Army aviation R&D activities, it is not necessary for the understanding of the efforts as presented in the Plan.

The Airmobile Systems section of the Plan is aligned to present the operational systems, developing systems, and R&D planning concepts as an element of the land combat functions of mobility, intelligence, firepower, combat service support, and command, control [illegible] communication rather than as individual systems. The Technology sections present the research eff[illegible]d, assuming no constraints on resources, to develop the technology base necessary to support the airm[illegible]em concepts. The Technology sections also provide a discussion of program planning and include the philosophy for the development of technical thrusts for the individual technologies. The Plan covers RDT&E activities (6.1 through 6.7 program categories) and also MM&T activities, which are normally part of Procurement of Equipment and Missiles-Army (PEMA).

Story C. Stevens

STORY C. STEVENS
Major General, USA
Commanding

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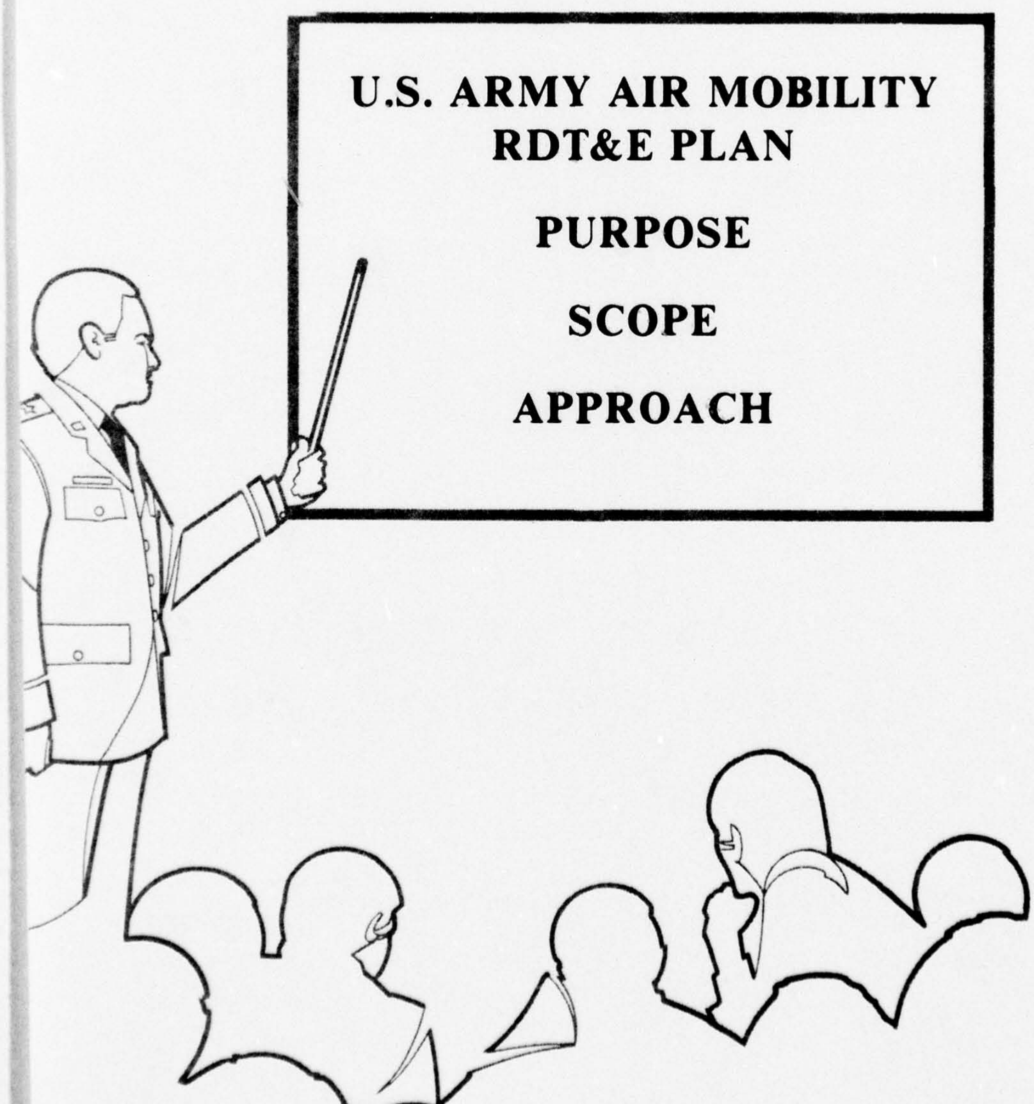

U.S. ARMY AIR MOBILITY
RDT&E PLAN
PURPOSE
SCOPE
APPROACH

PURPOSE

The Army Aviation RDT&E Plan is prepared by the U.S. Army Aviation Research and Development Command as its response to the requirement for the Consolidated R&D Plan described in the Joint CDC/AMC Materiel Need Procedures Handbook, March 1972.

Superiority of future Army airmobile systems depends on the availability and exploitation of new scientific knowledge, the nature and extent of which can only be estimated. The development of a firm technology base to meet projected requirements can be ensured by formulating a time-phased prediction of technical potential set forth in an orderly sequence of coordinated activities in the many disciplines and technologies required to develop airmobile systems. An objective of the Army Aviation RDT&E Plan is to provide such an evaluation of technical potential. The Plan presents an instantaneous assessment, and therefore requires continual review and updating to account for technological advances or changes in threat or policy for requirements.

The primary concepts emphasized during the preparation of this Plan are:

- The establishment of substantial research and exploratory development efforts directed toward the long-term satisfaction of technological deficiencies; vitalization of the technology base; and pursuit of aggressive policies, with innovation as appropriate, for stimulation of the productivity of the technology base.
- The initiation and continuation of specific prototypes, advanced technology demonstrators, and new initiatives to exploit promising new concepts and technology that are potentially capable of substantially affecting areas of significant force deficiency.
- The continued development, test, and evaluation of major systems with a substantial effort to orient programs for their development toward achievement of more realistic production, operational, and maintenance costs.

The Plan seeks to explore all feasible options for future systems, with the goal of providing knowledgeable elimination of options and identification of optimum concepts for development when required. The more distant the operational date, the more options are pursued and at the more fundamental research level.

The Plan is intended to be a management tool to be used in providing visibility of acknowledged requirements and interdependence of necessary technological achievements. Although the Plan establishes the basis for programming, it is not in itself a program. It is not constrained by available resources, but is the foundation on which a program can be structured within such constraints.

The Plan is dedicated to development of the best combat vehicles possible for the defense of this country. However, the planned developmental activities are undertaken with full awareness of the need to minimize any environmental degradation that might occur because of operation of these new systems. Great emphasis is placed on the reduction of noise and atmospheric pollution.

SCOPE

The Plan sets forth plans and objectives for Army aviation R&D activities for FY78 through 97, with particular emphasis on FY78 through 82.

The Plan addresses, and is in harmony with, the following documents:

- DA objectives, policies, and guidance for RDT&E including:
  - The Army Program Objectives Memorandum (POM).
  - The Army Strategic Objectives Plan (ASOP).
  - The Army Force Development Plan (AFDP).
  - The Army R&D Planning System (ARDPS), including the Threat Estimates, Army System Coordinating Documents (ASCODs), the Research and Technology Coordinating Document (RTCOD).
  - Catalog of Approval Requirements Document (CARDS) (including Operational Capability Objectives).
- Army Science and Technology Objectives Guide (STOG–78).
- Required Operational Capability (ROC), Development Plan (DP), and Materiel Need

(MN) documents, Training Device Requirements, and DA-approved QMDOs, ADOs, SDRs, and QMRs.

- HQ, DARCOM objectives, policies, and guidance provided by the annual DARCOM Planning Guidance document, the DARCOM Integrated R&D Plan, DARCOM RDTE program guidance and DARCOM Five Year Defense Plan (FYDP).
- TRADOC Combat Development Studies.

This Plan considers and is closely coordinated with R&D programs of the following U.S. Army organizations:

- Army Research Office (Engineering ·R&D group)
- Air Mobility Division, DCSRDA
- Army Materiel Development and Readiness Command (Aviation group)
- Army Materiels and Mechanics Research Center
- Mobility Equipment R&D Command
- Army Aeromedical Research Laboratory
- Ballistics Research Laboratory
- Human Engineering Laboratory
- Natick R&D Command
- Armament R&D Command
- Electronics R&D Command
- Missile R&D Command
- Troop Support and Aviation Materiel Readiness Command

In particular, activities are coordinated in the areas of Human Factors, Avionics, Ground Handling, and Weapons where performance requirements necessitate the integration of these factors into the total airmobile system, but where mission responsibility for R&D is in or shared with another commodity command or corporate laboratory.

The Plan is in consonance with foreign R&D and related activities, both from the standpoint of threat from a potential enemy and exploitation of Allied developmental efforts. The latter is achieved by active participation and communication with NATO countries through the Advisory Group for Aerospace Research and Development (AGARD) and The Technical Cooperation Panel (TTCP).

The Plan describes research, development, test, and engineering activities appropriate to Army aviation from fundamental research through operational system development. A description of RDT&E programs is included in Army Regulation 705–5. Because of the dependence of new structural and propulsion concepts on concurrent development of advanced manufacturing methods for proof of feasibility and economical fabrication of components, programs normally falling under the category of Manufacturing Methods and Technology (MMT) Engineering Measures are included in this Plan. MMT as a part of Procurement of Equipment and Missiles, Army (PEMA) is described in Army Regulation 37–100–72.

This Plan includes a Resources Required (RR) section that describes the funding and manpower requirements to accomplish the technological improvement goals identified in the Plan. Also included in most of the technology sections is a subsection on Laboratory Project Selection Process. This process provides Laboratory management with a systematic project selection procedure. The process is described in detail in the Technology Introduction section and is referred to as OPR-Objectives, Priorities and Rationale.

APPROACH

Planning is defined as selecting the appropriate organizational objectives and policies, determining the technical potential to satisfy them, and establishing procedures and methods for achieving those objectives. Technological forecasting, which is an implicit element of the planning process, can be approached by two different methods: (1) "exploratory" forecasting of technology, conjectural in nature, that seeks to project technology parameters from a base of accumulated knowledge in relevant areas; and (2) "normative" forecasting of technology, deterministic in nature, that is constrained by the objectives of future requirements. Generally, the latter approach is followed in the preparation of this Plan. In this process, future systems goals are identified and assessed to determine technological requirements (voids). By analyzing these requirements regressively through the R&D cycle, specific discipline and functional research requirements are identified; the research requirements then become the elements from which R&D programs can be developed.

This process has been typed "demand pull," since technological advance is generally accelerated by responding to specific needs. The two types of forecasting are complementary, not competitive, and both should be used. Consequently, although the motivating forces that directed this Plan are air mobility mission requirements, the Plan is also based on careful analyses of experience and observation, measurement, and interpretation of data, trends, and interactions of aviation technology.

Research and development planning cannot ignore future opportunities for producing technological advancements. It is worth noting that future threats and military operations are more affected by technological events than by the methods and tactics of previous situations. Therefore, the Plan reflects not only the response to the currently projected capability requirements, but also the need for a technological base that will stimulate innovative and imaginative airmobile missions, functions, and concepts.

Considerable uncertainty occurs in long-range planning in which some of the alternatives cannot be forecast. Technological breakthroughs, variations in threat projections, and fiscal constraints are areas of greatest uncertainty. Within the limitations of such uncertainties, this Plan provides for integrating the requirements for research to fill technical gaps and avoid nonessential duplication.

Current R&D efforts in Army air mobility are directed primarily toward the development of a family of aircraft, capable of vertical and short takeoff and landing, that can fulfill identified mission requirements for the five basic land combat functions of mobility, intelligence, firepower, combat service support, and command, control and communication. Efforts are conducted in physical, mathematical, environmental and life sciences, and in low-speed aeronautics, air-breathing propulsion, aircraft armament, vulnerability, survivability, crew protection, and support equipment. These efforts extend also into the fundamental research areas to generate increased knowledge for future air mobility concepts.

The approach taken for the preparation of the Plan is as follows:

- Desired Army aviation capabilities are identified in the form of projected missions and/or functions, without regard to specific candidate systems and with particular emphasis on current DA/DARCOM science and technology objectives.
- All apparent possible ways to perform each mission and/or function are determined.
- An anticipated IOC date in projected for each mission and/or function identified above. The most promising concepts, in terms of meeting the requirements, are then identified and discussed.
- The performance requirements and technical problem areas of each concept are interpreted in terms of technological requirements in 13 basic and supporting technologies:
  - Aerodynamics
  - Structures
  - Propulsion
  - Reliability and Maintainability
  - Safety and Survivability
  - Mission Support
  - Aircraft Subsystems
  - Weaponization
  - Man-Machine Integration
  - RPV Technology
  - Aviation Electronics
  - Manufacturing Technology
  - Mathematical Science
- Each of these 13 technologies was further divided into subdisciplines within which all work objectives can be categorized. The desired performance capabilities of the most probable systems are translated into quantitative technological requirements for each subdiscipline.
- The state of the art of each subdiscipline is defined quantitatively, where possible.
- Technology gaps are identified (i.e., the necessary quantitative improvements for each of these subdisciplines are defined with respect to the performance requirements for each system).
- Technology planning objectives are defined in each subdiscipline based on the technology gaps, technology forecast, and expert opinion regarding future potential based on extrapolation of existing trends. Wherever possible, quantitative improvement goals are defined in the form of key-parameter or quality-trend curves,

and the quantified objectives are related to the requirements of the future missions. In each area, consideration is given to the important causal factors and relationships with other disciplines and technologies.

- An orderly sequence of events by which the objectives can be attained is defined as a rational flow of activity from research through exploratory and advanced development. The objective is to demonstrate that the desired technology is sufficiently well in hand that subsequently required efforts will be primarily engineering in nature. Interfaces with other subdisciplines and major disciplines are identified. The dependence on, and effect of, developments in other technology areas are addressed, as well as the timing requirements on such interdisciplinary effects.

The above Plan preparation approach is portrayed in figure GI–1.

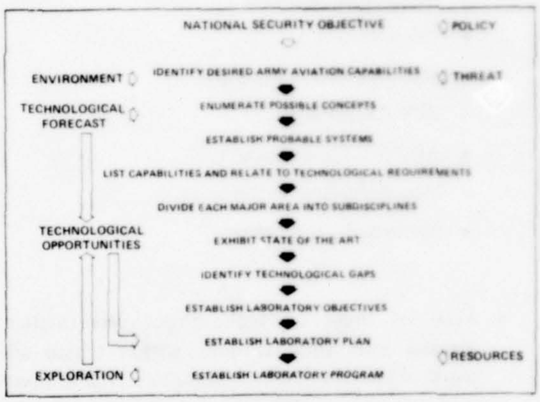


Figure GI–1. Preparation sequence for Army Aviation RDT&E Plan.

Technological program direction is included to provide program management an insight into the application of the tools provided in the Plan toward program planning. As stated previously and repeated for emphasis, the Plan establishes the basis for programming but is not in itself a program. All of the ingredients necessary for program planning are introduced for most of the technology areas and major technical trusts evolved via the OPR process.

Synopses of the Army Research and Technology Laboratories 6.1, 6.2, and 6.3 current projects and some AVRADCOM projects have been included in the applicable technological sections. FY78 Command Schedule funding is also shown for the various projects.

Progress in improving the performance of Army aircraft is paced by the technological advancements in the 13 basic and supporting technologies discussed above. Advances in state-of-the-art technology can only be made if the technology is validated by component or system demonstration in actual or simulated flight conditions. The Advanced Technology Demonstrator section of the Plan discusses the technological advances that will be validated on demonstrator aircraft or by simulation.

The Plan is presented in the following order:

- Development of airmobile systems is first described in the systems section.
- Technological discussion and program direction with objectives are then described in the technology sections.
- Finally, resource requirements to achieve these objectives are presented.

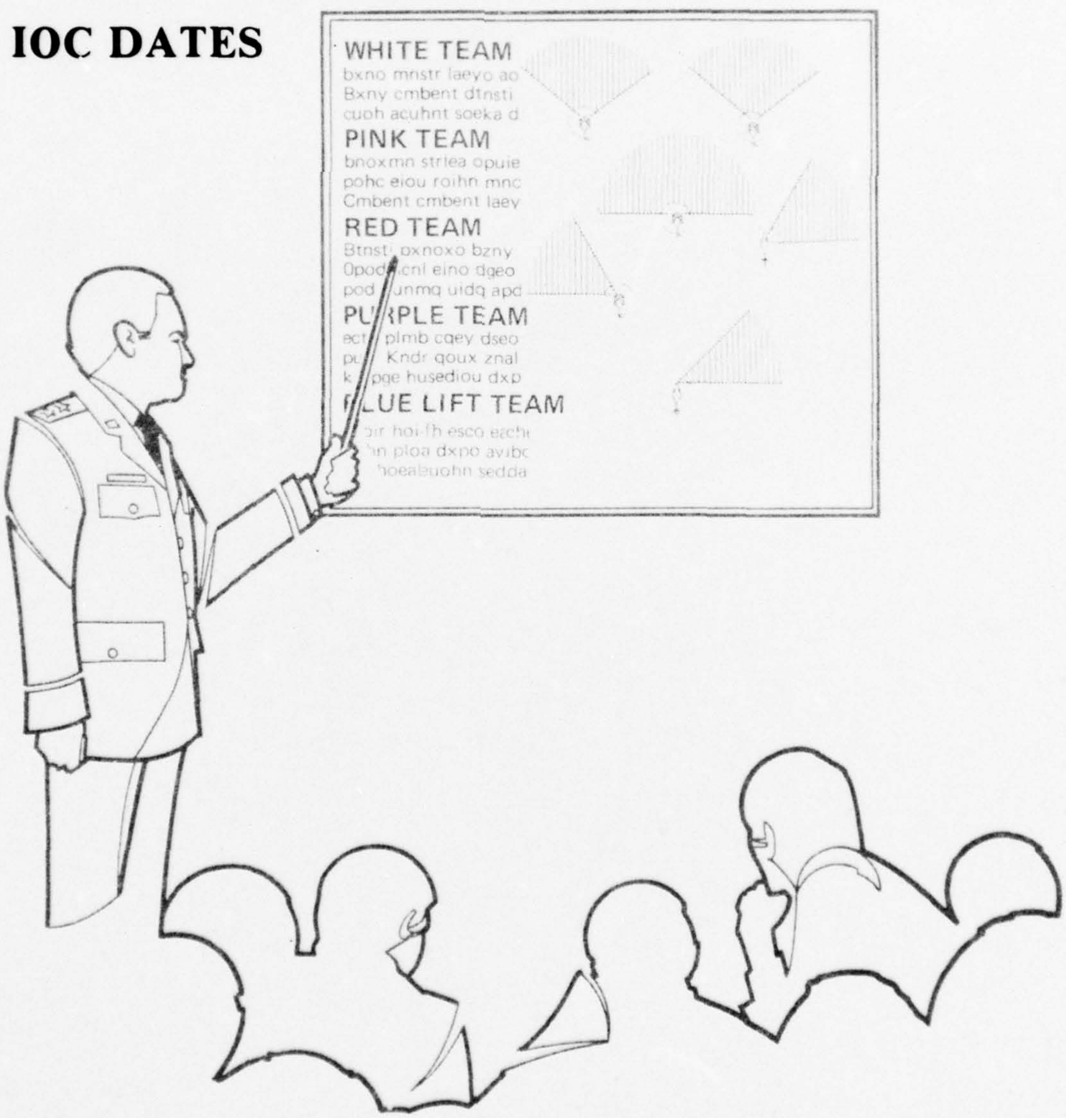
ARMY AVIATION SYSTEMS REQUIREMENTS

THREAT

LAND COMBAT FUNCTIONS

MAJOR THRUSTS

IOC DATES



ARMY AVIATION SYSTEMS REQUIREMENTS

The use of air vehicles by ground forces has added another dimension to the battlefield by enhancing the ability to conduct land combat functions. The traditional functions of land combat include mobility, intelligence, firepower, combat service support, and command, control, and communication. Use of Army aviation by ground forces is based on certain fundamental concepts of employment of aviation resources that include the following:

- Aircraft are integrated into ground units. Under this concept, aircraft are considered equipment used as an integral part of land combat. The use of airspace is transitory and directly related to the performance of land battle.
- Army policy is to assign aircraft to the lowest user level that can demonstrate a full-time use of the aircraft and that can accommodate and support it.
- The aircraft should perform its functions by placing the least possible burden on the ground element for support.

As a consequence of the above concepts, and as a result of Army experience with aviation in combat, certain additional criteria have been developed that bear directly on required aircraft characteristics. These characteristics for vertical takeoff and landing (VTOL) aircraft include the following:

- The ability to hover out of ground effect at 4,000 ft pressure altitude, 95° F at basic mission weight with a 500-ft/min vertical rate of climb and 95 percent intermediate power, thus permitting aircraft to be based close to the tactical user without prepared airfields.
- Adequate speed to ensure timely response, productivity (ton miles per hour, missions per day, etc.), and survivability. Generally, high speed is desirable but can be costly in terms of power required, design complexity, dynamic component life, and direct costs such as forward area refueling support, airframe costs, maintenance costs, and size/weight of aircraft. High speed must be justified in terms of reduced aircraft losses and in increased cost effectiveness of overall mission performance.
- All-weather, full-instrument flight capability providing effective organic aviation support to the ground soldier under any climatic condition in which he fights.
- Crashworthiness, requiring prevention of post-crash fires, energy-absorbing structures for crash impact, and crew restraining devices to enhance survival.
- Survivability, requiring the ability to survive enemy fire without high penalties in terms of aircraft weight, size, or costs.
- Terrain flying, requiring the ability for flight in such a manner as to utilize the terrain, vegetation, and man-made objects to enhance survivability by degrading the enemy's ability to visually, optically, or electronically detect or locate the aircraft. This requirement is applicable to cargo handling aircraft systems as well as combat oriented systems.

The three operational concepts require that Army aircraft meet the user's functional needs, that they possess characteristics that permit the user to have ready access to the aircraft, and that they do not place great demands on the user for support. Considerations such as these are the genesis of Army requirements documents for such characteristics as VTOL, simplicity, reliability, and maintainability. For the aircraft characteristics, the requirement to hover originates directly from the need that the aircraft be based with the user, that it be immediately responsive in terms of time, and that it minimize demands on the user for airfield construction or protection. The aircraft should be capable of existing within the normal perimeter of tactical ground units. This concept of livability translates directly into characteristic requirements for low-disc-loadings and low noise levels. Related characteristics are those of agility and maneuverability in the air and on the ground.

The concept of minimal special support generates characteristics related to ground support maintainability, simplicity, and reliability. The effect of these characteristics on capability must be carefully assessed through trade-off studies. Advances in the state of the art must provide the additional benefits without the penalties that would reduce the effectiveness of Army aviation.

THREAT

The Army in the future will have a continuing need for new and improved materiel systems to enable it to fulfill its role in the national defense. In order that a proposed weapon system be established as a worthwhile addition to the Army inventory, careful consideration of potential adversary capabilities and intentions must be a part of the development process. Simply stated, the Army has to be aware of the threat and take measures to reduce or negate it.

For R&D considerations, we must know the capability differences between our systems and those of a possible enemy, and must know as much as possible about how their materiel operates and mode of deployment. Furthermore, we must consider these factors up to 10–20 years in the future. The threat is "what you shoot at and what shoots at you," and any countermeasures that would reduce the effectiveness of our systems. It is a key facet of the developmental process and is applicable throughout the life cycle of Army materiel.

As illustrated in figure AI–1 (a graphic side view of the threat as it might exist on a high threat battlefield), the Army pilot is being trained to negate the effect of the threat as much as possible by tactics and by flying techniques. It is not enough by itself. In order to be mission-effective, the same Army pilot must have the equipment to do the job. Close coordination between developer and user of Army Aviation Systems ensures not only awareness of the threat but acting on the threat.

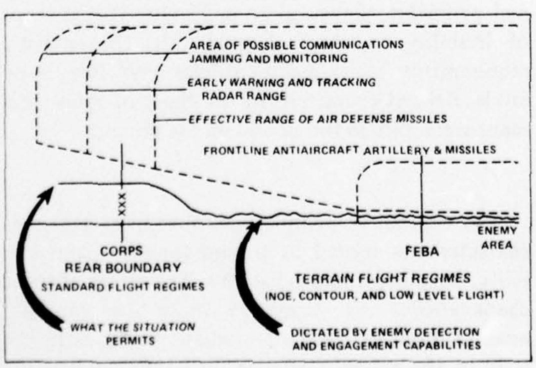


Figure AI–1. Threat profile.

Threat as a generic term is vast when applied to Army aviation. It encompasses hostile weapons such as ground based guns, surface to air missiles (SAM), and air to air guns/missiles, and also those systems and techniques which could negate or lessen our abilities such as electronic warfare (EW). Since the threat is not limited to fielded system but includes those weapons which will be fielded in the future, the potential impact of ignoring the threat in the R&D process becomes disastrous.

The latest threat information available has been used in the generation of this Plan. It is based primarily on the threat analysis document "Threat to US Army Aviation Systems" (U) prepared by Department of the Army, Assistant Chief of Staff Intelligence. The threat is not static however, and is constantly updated with the information being used in actual R&D activities.

LAND COMBAT FUNCTIONS

GENERAL

The application of operational airmobile systems to the various land combat functions is shown in figure AI–2 and discussed in detail in the following section – Airmobile Systems. The matrix of figure AI–2 as well as the discussion material is based on the five land combat functions of mobility, intelligence, firepower, combat service support, and command, control and communication. The airmobile systems are categorized as operational systems, developing systems and R&D planning concepts. There is mission overlap between some of the functions which, in turn, results in the same aircraft applicability.

LAND COMBAT FUNCTION	MISSION	OPERATIONAL SYSTEMS	DEVELOPING SYSTEMS				R&D PLANNING CONCEPTS							
			AAH	UTTAS	RPV	CH-47D*	ASH	HLH	OV-X	SUR/VTOL	AAWS	LAH	LUH	ITAV
MOBILITY	UTILITY	UH-1		■									▨	
	MEDIUM LIFT	CH-47				■								
	CARGO TRANSPORT	CH-54						▨						
INTELLIGENCE	RSTA/D	LOH					■			▨				
		OV-1D			■				▨					
FIREPOWER	TACTICAL MOBILITY	UH-1	■									▨		
	DESTROY	AH-1	■								▨			
COMBAT SERVICE SUPPORT	UTILITY	UH-1		■									▨	
	MEDIUM LIFT	CH-47				■								
	CARGO TRANSPORT	CH-54						▨						
COMMAND, CONTROL & COMMUNICATION	AVIATION SUPPORT	LOH											▨	▨
		UH-1		■									▨	

*MAJOR MODERNIZATION PROGRAM

Figure AI–2. Land combat function mission systems.

MAJOR PROGRAM THRUSTS

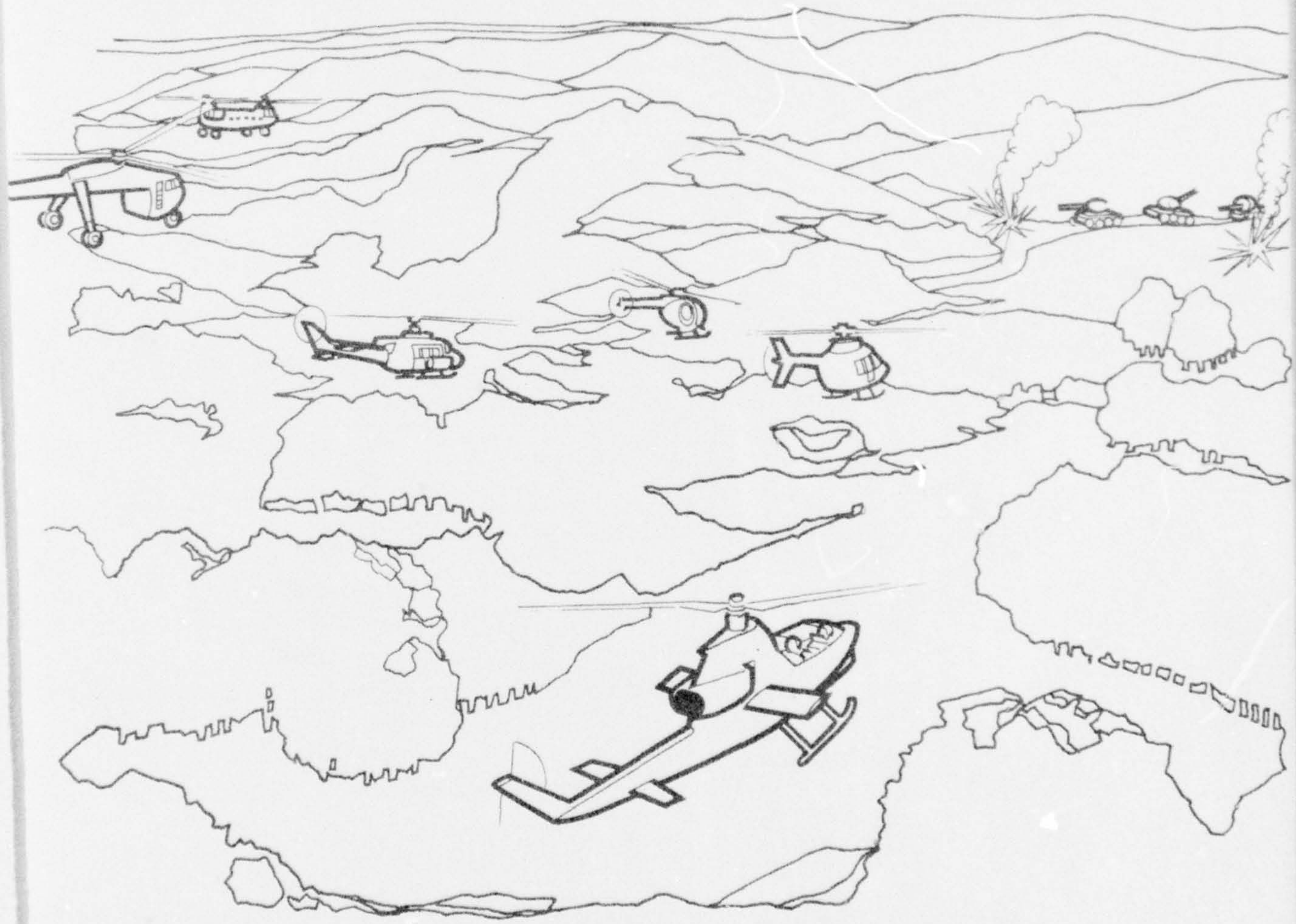
There is a commonality among the deficiencies and shortcomings of current Army aircraft; included are lack of survivability, high life-cycle costs, and inadequate performance. A similar analysis of potential problem areas for future systems results in similar common problem areas. Solution of all the problem areas would require greater resources than may be available to the DARCOM. Consequently, emphasis has been placed on the DA specified science and technology objectives, with the greatest effort being applied in the areas where technological breakthroughs or advances would significantly improve the combat capability of current or developing aircraft systems.

As a result of the emphasis placed on the current major thrusts, R&D efforts may resolve or reduce the significance of a particular problem. At that time the thrusts should be realigned in recognition of new areas that promise the highest potential payoff. The identification of problems presented in this Plan provides a method of identifying these areas.

IOC DATES

IOC dates for developing airmobile systems and R&D concepts used in the development of this Plan are classified, in most cases, and have not been included. However, in the formulation of the Plan, it has been assumed that, on the average, a period of 8 years is required from contract definition to IOC and initiation of exploratory development is required about 7 years prior to contract definition.

INTRODUCTION
MOBILITY
INTELLIGENCE
FIREPOWER
COMBAT SERVICE SUPPORT
COMMAND, CONTROL AND COMMUNICATIONS



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INTRODUCTION

The basic objectives of Army aviation units are to augment the capability of the Army to:

- Conduct prompt and sustained land combat
- Provide the ground commander with mobility, firepower, and staying power needed to win the first battle
- Help the ground forces win when outnumbered

In the future, Army aviation units will fight as part of the Combined Arms Team in a high threat environment. To provide the Army with this capability, the R&D efforts must be aimed at system development rather than individual aircraft development.

This section of the RDT&E Plan presents a brief summary of the Army aviation current systems, developing systems, and R&D planning concept systems (projected future aircraft system). Since this is an R&D planning document, emphasis is placed on developing technology for the projected future aircraft systems. This section is organized around the five basic land combat functions as discussed in the Airmobile Systems Introduction – mobility; intelligence; firepower; combat service support; and command, control, and communication. As one would expect, there is mission overlap between some of the various functions which, in turn, results in the same aircraft applicability to various functions. This is presented graphically in figure AI–2.

This section is arranged to present a brief discussion of each of the five land combat functions and their corresponding airmobile systems. A detailed analysis and discussion of each of the systems is then presented by table and/or text. The location of the discussion material for a particular system within the individual land combat function is identified in a table for each system pertaining to a particular combat function.

MOBILITY

The demand for greater mobility has continuously increased throughout the history of warfare. The airmobile capability that began in the Korean conflict and proved so valuable during the recent experience in Vietnam will be equally, if not more valuable in the future. The ability to quickly redeploy light mechanized units and mobile air defense artillery by air, to transport assault troops, weapons, and equipment around the battlefield and over obstacles, and to bypass enemy strong points should prove particularly valuable in any future conflict.

For squad-size units and small weapons, the utility mission of the mobility function is currently being performed by the UH-1, which will be replaced by the Utility Tactical Transport Aircraft System (UTTAS). The UTTAS will lift a basic tactical infantry squad or its transport equivalent of externally or internally loaded bulk cargo. For units of larger size or heavier weapons, the CH-47 provides the necessary mobility and medium lift. Because of its vulnerability, the CH-47 is rarely used in the combat assault role; rather it provides maneuverability to the fire support elements and other supporting units. The CH-47 modernized Medium Lift Helicopter (MLH) (to be designated as the CH-47D) is projected to replace the CH-47 for payloads in the 7- to 10-ton range. For large outsized loads requiring external slinging, the CH-54 helicopter is currently used.

Although there are no AVRADCOM R&D efforts that directly relate to the future utility mission system, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed for a future utility system. In addition, a Light Utility Helicopter (LUH) with high performance characteristics and agility is also needed to assume many of the missions associated with mobility, combat service support, and command, control and communications. For future R&D system planning for cargo transport, the Heavy Lift Helicopter (HLH) System is projected for lift capability of 20-50 tons.

AIRMOBILE SYSTEMS

Table AM–A summarizes the current operational systems, developing systems, and R&D planning concepts and locates the discussion material for each system.

TABLE AM–A
MOBILITY SYSTEMS

TYPE	MISSION	SYSTEM	DISCUSSION MATERIAL	
			TYPE	LOCATION
Current Operational Systems	Utility	UH-1	Table AM-F	Pg AM-7
	Medium Lift	CH-47	Table AM-G	Pg AM-7
	Cargo Transport	CH-54	Table AM-H	Pg AM-8
Developing Systems	Utility	UTTAS	Text	Pg AM-8 to -13
	Medium Lift	CH-47D	Text	Pg AM-13 to -18
	Cargo Transport	See Note 1	–	–
R&D Planning Concepts	Utility	Tilt Rotor	Text	Pg AM-18
		LUH	Table AM-O	Pg AM-20
	Medium Lift	See Note 2	–	–
	Cargo Transport	HLH	Text	Pg AM-19 to -22

NOTES:

1. There are no cargo transport helicopter system development efforts under consideration by AVRADCOM R&D at this time.

2. There are no medium lift aircraft systems under consideration by AVRADCOM R&D as a replacement for the CH-47 Modernized Medium Lift Helicopter.

INTELLIGENCE

Army aviation performs its intelligence function by collecting and gathering intelligence for the ground commander and for the acquisition and designation of targets for engagement by armed helicopters and other firepower means. The primary mission for this combat function is reconnaissance, surveillance, target acquisition and designation (RSTA/D). In addition, electronic warfare, decoy, and communication relay can be classified under this function although there is a definite overlap between intelligence and command, control and communications for some of the mission requirements.

The key requirements for this function are good visibility, aircraft agility, simplicity, survivability, and ability to fly under conditions of reduced visibility and darkness. For the longer range intelligence gathering mission, the requirements are survivability, precise navigation, dash speed, and ability to carry sophisticated sensors providing real time readout of targets to ground stations.

Currently, this function is being performed by the OH-58 and OH-6 Light Observation Helicopters (LOH) and for the standoff mission, by the OV-1D Short Takeoff and Landing (STOL) airplane. A draft LOA is being staffed for a replacement for the OV-1D. Remotely Piloted Vehicles (RPV) are being developed to perform this function for operation in the high threat environment.

An advanced Scout-type aircraft is required for operation in air cavalry, attack helicopter, and field artillery units. The Advanced Scout Helicopter (ASH) is in the R&D planning concept stage to fulfill this requirement.

The OV-X system will only provide standoff mission capability operating from a fixed site. For penetration missions, VTOL capability will become a prime requirement. A candidate R&D planning concept configuration for a manned VTOL platform is the tilt-rotor concept identified as a Surveillance VTOL Aircraft System (SUR/VTOL).

Table AM–B summarizes the current operational systems, developing systems, and R&D planning concepts and locates the discussion material for each system.

TABLE AM–B
INTELLIGENCE SYSTEMS

TYPE	MISSION	SYSTEM	DISCUSSION MATERIAL	
			TYPE	LOCATION
Current Operational Systems	RSTA/D	LOH	Table AM-Q	Pg AM-24
		OV-1D	Table AM-R	Pg AM-24
Developing Systems	RSTA/D	RPV	Text	Pg AM-22 to -31
R&D Planning Concepts	RSTA/D	ASH	Text	Pg AM-31 to -33
		OV-X	Text	Pg AM-32 to -33
		SUR/VTOL	Table AM-W	Pg AM – 35

FIREPOWER

The firepower function as used herein includes two mission definitions. One is to destroy or disrupt enemy armor and mechanized forces by aerial firepower and the other is to provide tactical mobility and to support air assault or airmobile operations throughout the battle area.

Currently, Army aviation provides firepower via the AH-1G Cobra armed helicopter. Greater capability, particularly in the antitank role, will be provided by the AH-1Q (Cobra-TOW) as an interim system. Key factors are the discriminating nature of direct aerial fire support: to be close in, highly responsive, and available in all-weather and at night. The Advanced Attack Helicopter (AAH) provides increased firepower, flexibility, increased survivability, and all-weather operation. The UH-1 has in the past been used to provide the Army with tactical mobility capability.

The employment of Army aviation units in a high threat environment will have the greatest effect on the attack helicopter in meeting the Army aviation objective of providing the commander with the mobility, firepower, and staying power needed to win the first battle. Increased emphasis must be placed on survivability, particularly through terrain flying techniques. However, other system requirements such as dash speed and endurance must not be overlooked.

R&D efforts are necessary to continue technological improvements in the systems key performance factors. Advancements in weapons, sensors, propulsion, aerodynamics, and structures as well as in tactics may well cause the AAH to be behind the state of the art in the early 1990s. One postulated R&D planning concept for the replacement of the AAH is the Advanced Aerial Weapons System (AAWS). This vehicle would most likely be a multi-engine aircraft with VTOL capability for operation in and out of

forward bases. To attain the desired dash speeds, conversion to an airplane type operation is indicated. Possible aircraft concepts include augmented thrust helicopter, tilt rotor, tilt wing, and deflected thrust. Possible weapons include advanced fire-and-forget missiles, antimissile missile, and air-to-air weapons.

To provide a complete combined arms team, R&D planning efforts should include a Light Attack Helicopter (LAH) to supplement the AAH by providing economical armed reconnaissance and fire support to small combat units.

Table AM–C summarizes the current operational systems, developing systems, and R&D planning concepts and locates the discussion material for each system.

TABLE AM–C
FIREPOWER SYSTEMS

TYPE	MISSION	SYSTEM	DISCUSSION MATERIAL	
			TYPE	LOCATION
Current Operational Systems	Tactical Mobility	UH-1	Table AM-F	Pg AM-7
	Destroy	AH-1	Table AM-X	Pg AM-36
Developing Systems	Tactical Mobility	AAH	Text	Pg AM-33 to -40
	Destroy			
R&D Planning Concepts	Tactical Mobility	LAH	Text	Pg AM-42
	Destroy	AAWS	Text	Pg AM-41 to -42

COMBAT SERVICE SUPPORT

This function provides the traditional combat service support function of providing an airline of communication capable of delivering supplies from a rear storage area to the immediate vicinity of the user. The "retail" delivery of high priority cargo to the company and platoon areas is accomplished by utility helicopters; cargo helicopters (CH-47, CH-54) perform the "wholesale" bulk delivery of high priority cargo. Relatively short distances are involved, but within inhospitable environment and terrain. Fixed bases are generally not available; hence, VTOL capability is a requirement. In this respect, the prime mission of the large cargo helicopters would be the delivery of containerized cargo from offshore positions, across the beach, and to forward supply areas. This capability is particularly advantageous when port and transport facilities are either inadequate or unavailable. In addition, the recovery of damaged equipment or captured enemy material can be accomplished by the larger cargo helicopters. For transport of supplies to the forward area in a high threat environment, a system capable of carrying external loads in nap-of-the-earth flight profiles and in day-night all-weather conditions while remaining masked is required in lieu of internal cargo transport. The system must be flexible and provide rapid response to unit operations; for example, the transport of field artillery, air defense units, antitank elements as well as bulk material about the battlefield. The cargo handling systems must be automated to the maximum extent possible to eliminate ground handling crews and to provide rapid load engagement, thus obviating the need for long periods of helicopter hovering or precise over-a-spot hover performance.

Table AM–D summarizes the current operational systems, developing systems, and R&D planning concepts and locates the discussion material for each system.

TABLE AM–D
COMBAT SERVICE SUPPORT SYSTEMS

TYPE	MISSION	SYSTEM	DISCUSSION MATERIAL	
			TYPE	LOCATION
Current Operational Systems	Utility	UH-1	Table AM-F	Pg AM-7
	Medium Lift	CH-47	Table AM-G	Pg AM-7
	Cargo Transport	CH-54	Table AM-H	Pg AM-8
Developing Systems	Utility	UTTAS (1)	Text	Pg AM-8 to -13
	Medium Lift	CH-47D	Text	Pg AM-13 to -18
	Cargo Transport	See Note (2)	–	–
R&D Planning Concepts	Utility	LUH (3)	Table AM-O	Pg AM-20
	Medium Lift	See Note (4)	–	–
	Cargo Transport	HLH (5)	Text	Pg AM-19 to -22

NOTES:

1. The UTTAS, which is under development as a utility helicopter, will fulfill the utility mission of the *combat service support function. However, usage and mission equipment will vary as the need dictates.*

2. There are no cargo transport helicopter system development efforts under consideration by AVRADCOM R&D at this time.

3. Although there are no AVRADCOM R&D efforts that directly relate to a future utility mission for the combat service support function, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed. In addition, a Light Utility Helicopter with high performance characteristics and agility is needed to assume many of the missions associated with mobility, combat service support, and command, control and communication.

4. There are no medium lift aircraft systems under consideration by AVRADCOM R&D as a replacement for the CH-47 Modernized Medium Lift Helicopter.

5. The Heavy Lift Helicopter concept is needed to satisfy future cargo transport mission, associated with the combat service support functions.

COMMAND, CONTROL, AND COMMUNICATIONS

The function of command, control, and communication (C^3) is made more challenging to the Army commander by the far-ranging operations envisioned for an expanded battlefield with minimum warning and preparation time and under all-weather, day and night conditions. Rapid movements and immediate response are required to supervise a widely dispersed operation. Radio communications from existing airmobile systems is greatly degraded under some environmental conditions and during terrain flying. For future operations, the C^3 capability must be improved and must be expanded down to the company level.

Currently the command, control, and communications function is performed by the light observation

helicopter and the UH-1 helicopters. The observation helicopter is ideal for providing the commander with liaison, courier, and radio relay capabilities. In emergencies, the LOH can carry limited personnel and cargo. It provides the commander with a command and control platform. The UTTAS and improved version of the LOH (OH-58C) are projected to perform this role for the battalion and higher commanders.

R&D Planning Concepts, at the battalion level, would include a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, and a Light Utility Helicopter with high performance characteristics and agility. At the company level, operational requirements dictate a simple small individual tactical aerial vehicle (ITAV) system with operational requirements including hover capability and operation in adverse weather conditions and terrain flying environment. The Army's Training and Doctrine Command continues to evaluate, from a conceptual point of view, the potential battlefield applicability of advanced technology developments in all areas, including airmobility.

Table AM–E summarizes the current operational systems, developing systems, and R&D planning concepts and locates the discussion material for each system.

TABLE AM–E
COMMAND, CONTROL, AND COMMUNICATIONS SYSTEMS

TYPE	MISSION	SYSTEM	DISCUSSION MATERIAL	
			TYPE	LOCATION
Current Operational Systems	Battalion Level	LOH	Table AM-Q	Pg AM-24
		UH-1	Table AM-F	Pg AM-7
	Company Level	None	–	–
Developing Systems	Battalion Level	UTTAS (1)	Text	Pg AM-8 to -13
	Company Level	None	–	–
R&D Planning Concepts	Battalion Level	Tilt Rotor (2)	Figure AM-14	Pg AM-44
		LUH (3)	Table AM-O	Pg AM-20
	Company Level	ITAV (4)	Table AM-AD	Pg AM-44

NOTES:

1. The UTTAS, which is under development as a utility helicopter, will perform the aviation support mission of the command, control and communications functions for the battalion commander and higher echelon levels.

2. Although there are no AVRADCOM R&D efforts that directly relate to a replacement aircraft for the UTTAS, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed.

3. A Light Utility Helicopter with high performance characteristics and agility is needed to assume many of the missions associated with aviation support as well as mobility and combat service support.

4. As a part of a separate activity, the Army Training and Doctrine Command is currently analyzing the potential requirements for an individual lift device in certain of the Army's missions. The results from this analysis will be considered in future R&D efforts in the small vertical lift device field.

MOBILITY SYSTEMS

CURRENT OPERATIONAL SYSTEMS

UTILITY MISSION – UH-1H

The current standard Army aircraft performing the utility mission of the mobility function is the UH-1H helicopter. A discussion of the UH-1H is presented in table AM–F.

MEDIUM LIFT MISSION – CH-47C

The CH-47C is the current Army medium lift helicopter (MLH). A discussion of the CH-47C is provided in table AM–G.

TABLE AM–F
CURRENT UTILITY HELICOPTER DESCRIPTION

GENERAL	• The current standard utility helicopter is the Bell UH-1H.
PRESENT CAPABILITIES	• The UH-1H is capable of carrying 8 to 10 combat equipped troops, or 2,400 lb of cargo more than 250 miles at a cruise speed of 100 knots. It has an external cargo hook capable of lifting 4,000 lb and is equipped for IFR flight. Large sliding doors and unobstructed cargo space allow rapid loading and unloading of internal cargo and combat troops.
DEFICIENCIES AND SHORTCOMINGS	• The major deficiency of the UH-1 helicopter has been its inability to achieve the slated performance and payload, with reserve power for OGE vertical climb at higher density altitudes. The addition of a copilot, two door gunners, aircrew armor, and associated equipment has reduced the effective payload of the UH-1 to six to eight combat equipped troops, or less than 2,000 lb of cargo. Also, the UH-1 has a distinctive noise signature (blade slap) easily identifiable with this helicopter. The maintenance MMH/FH ratio is excessive and the MTBF of major components is inadequate. The installation of crashworthy fuel cells and IR-suppression devices have increased its survivability, but it is still marginal.
FOLLOW-ON SYSTEM	• The UH-1H will be replaced by the UTTAS as the Army utility helicopter.

TABLE AM–G
CURRENT MEDIUM LIFT HELICOPTER DESCRIPTION

GENERAL	• The current Army medium lift helicopter is the Boeing-Vertol CH-47C.
PRESENT CAPABILITIES	• The CH-47C is capable of carrying 34 troops, or an internal cargo of 10 tons for a 100-nautical-mile radius mission, at 120 knots. It can also lift 23,300 lb for a 20-nautical-mile mission at 100 knots. It has a 30-ft-long cargo comparemtn capable of carrying 2 3/4-ton trucks or other large bulky cargo. It has an external cargo hook of 10-ton capacity that may also be used for towing operations. The aircraft has a self-contained APU and is fully IFR-equipped.
DEFICIENCIES AND SHORTCOMINGS	• Operating costs of the current CH-47 fleet are excessive. A and B series aircraft are approaching planned retirement and their lift capability is less than optimum to support ground forces. Safety and survivability and RAM features of the existing CH-47's are inadequate and need to be upgraded.
FOLLOW-ON SYSTEM	• The LTTAS was planned to replace the CH-47C; however, this role was abandoned when the LTTAS effort was terminated in 1970. The Army has reviewed the CH-47 operational capability and concluded that a valid requirement exists to sustain a MLH fleet well into the 1990's. As a result, the modernized CH-47(D) is now programmed to replace the CH-47 fleet. This program has DA approval and a contract has been awarded to Boeing-Vertol for engineering development of 3 prototype aircraft.

CARGO TRANSPORT MISSION – CH-54B

The CH-54B is the current Army cargo transport helicopter. A discussion of the CH-54B is presented in table AM–H.

DEVELOPING MOBILITY SYSTEMS

UTILITY MISSION – UTTAS

General. The Utility Tactical Transport Aircraft System (UTTAS) will possess essential performance, maintenance, and physical characteristics required to operate primarily as a squad carrier for airmobile operations in all intensities of conflict in the assault and resupply phases and secondarily as combat support and combat service support for other units and agencies. It must be capable of performing its intended missions under adverse geographical and environmental conditions.

The UTTAS will be transportable by sealift or airlift with minimum disassembly. Its physical dimensions will allow two aircraft to be loaded in a C-141 or one on a C-130. Preparation time per UTTAS will not exceed 5 man-hours within a 1.5-hr period and reassembly will not exceed 5 man-hours within a 2-hr period. The actual loading time for one UTTAS will not exceed 30 min.

Other characteristics will include sufficient agility and maneuverability to permit safe nap-of-the-earth operation at 150 knots formation flight under visual conditions, and instrument flight (day and night) up to the aircraft service ceiling.

Salient Characteristics. Performance, reliability and maintainability characteristics and physical characteristics of UTTAS are presented in tables AM–I and AM–J, respectively.

Throughout the preliminary design study and analysis resulting in the configuration described in table AM–J, the primary objective was to produce a UTTAS with maximum survivability. To achieve this, three major parameters were considered.

- Signature reduction through infrared suppression will be engineered into the system by reducing surface emissivity of the engine group. A removable kit-type IR emission suppressor will be provided for the engines. The structural design of the baseline aircraft presents a minimum radar cross section by means of geometrical shaping to eliminate specular surfaces and corner reflectors. Particular attention is required in the main rotor and tail rotor design to preclude blade slap, and rotational and tip vortex produced noises.
- Vulnerability as established by analysis, considering crew and vital component protection,

TABLE AM–H
CURRENT CARGO TRANSPORT HELICOPTER DESCRIPTION

GENERAL	• The current standard Army cargo transport helicopter is the Sikorsky CH-54B. The CH-54A is also in service.
PRESENT CAPABILITIES	• The CH-54B is equipped with a four-point load suspension system of 20,000 lb capacity and a single-point hoist with a capacity of 25,000 lb. It can carry a 25,000 lb external load for 20 nautical miles at 95 knots, or a smaller load of 15,000 lb for 120 nautical miles. Although its primary mission is external cargo, the CH-54 does have a detachable pod that can be readily attached or detached for internal cargo. The aircraft features a load-facing crewman who has limited control for hook-up and detaching of external loads. The aircraft has a self-contained APU and is fully IFR-equipped.
DEFICIENCIES AND SHORTCOMINGS	• The CH-54B, operational readiness averages only 75%. Contributing factors are low field density and an out of production status. Additionally, its maintenance MNH/FH ratio and SFC are relatively high, its cost per ton mile is higher than surface modes and it cannot carry passengers and external loads simultaneously.
FOLLOW-ON SYSTEM	• There is currently no system being developed to replace the CH-54B although Advanced Technology Components of a HLH system have been under development.

TABLE AM–I
UTTAS PERFORMANCE/RAM CHARACTERISTICS

OPERATIONAL CAPABILITY	• Low life cycle cost with squad lift capability.
PERFORMANCE CHARACTERISTICS	• Hover OGE at 4000 feet 95°F, VROC 450-550 fpm at 95% intermediate power, zero wind. • 145-175 knot cruise speed. • Three-man crew. • Payload 11 troops or 2,640 lb. • 2.3 hours endurance. • Safe one-engine inoperative capability. • All-weather day and night mission capability.
MAINTENANCE	• Fault corrective maintenance Unit and intermediate levels not to exceed 2.8 maintenance manhours per flight hour (MMH/FH) (exclusive of avionics and weapons subsystems). • Inspections and servicing Daily/preflight, periodic, and special inspections and servicing not to exceed 1 MMH/FH. 300 hr between periodic inspection. • Overhaul Mean time between removal of critical components greater than 1,500 hours. No major overhaul intervals by design less than 4,500 hours.
RELIABILITY	• Mission reliability greater than 0.986909*. • Flight reliability greater than 0.999952*. • Operational availability greater than 82%**.

*Based on completing a 1-hour mission while being supported by the maintenance environment found at any level of conflict.

**Utilizing the combination of modular components, diagnostic fault detection equipment, and simplified maintenance procedures.

resulted in a protective armor system for the baseline vehicle contained within the normal contours of the aircraft and retaining the maximum visibility afforded from the crew position. Critical elements, components, and equipment in the fuselage of the baseline configuration will be arranged, grouped or routed to achieve the minimum probability of being hit by ground fire small arms projectiles. Where critical items cannot be adequately protected through location, grouping, etc., armor protection devices have been incorporated. This armor for component protection has been included in the empty weight of the baseline configuration. Small items essential to continued flight and control of the baseline vehicle (i.e., control torque tubes, rod ends, engine governors, bell cranks, etc.), are to be afforded maximum protection from damage by enemy action by replacing such components with ballistic-resistant materials or by placing them behind heavy structures of noncritical items or components. When control system components are duplicated, they are to be separated to avoid damage by the same projectile.

• Safety and crashworthiness studies of accident investigation reports indicate that improvements in crash survival for crew and troops can be made if consideration is given in the initial

TABLE AM–J
UTTAS PHYSICAL CHARACTERISTICS

FUSELAGE/CABIN ARRANGEMENT	• Fuselage arrangement, structural and functional, shall be such as to accommodate the crew (pilot, copilot, and crew chief/gunner) and troop payload (11 combat-equipped troops @ 240 pounds each or an equivalent payload). A fourth crew station will be provided and occupied by the eleventh passenger or an additional gunner. • The UTTAS shall incorporate a 8000-pound capacity external cargo hook and provisions for mounting a 600-pound capacity rescue hoist. • Cabin arrangement shall incorporate 10 troop seats (minimum width of 20 inches) and two gunner positions. Complete provisions for 3 additional troop seats are provided. The cabin will also accommodate four to six standard folding, rigid pole litters. The floor will be of a nonskid material capable of supporting distributed loads of 300 psf. • Doors will permit rapid troop ingress and egress and in conjunction with the cabin arrangement will permit 11 combat-equipped troops to load or unload in less than five seconds.
LANDING GEAR	• Landing gear configuration will be wheeled with brakes, flotation capability or being towed across soil with a CBR of 2.5, minimum ground-to-aircraft fuselage clearance of 16-20 inches, ground-to-floor height of not more than 28 inches, and operational capability of 12° slope landing.
FUEL SYSTEM	• The fuel system shall comply with the latest military standard for crashworthy design. The system will have single-point pressure fueling and defueling, gravity fueling and defueling as well as closed-circuit fueling. It will accept range extending tanks.
POWERPLANT	• The UTTAS powerplant will use the advanced technology that has been developed by the Army's 1500 HP advanced technology gas turbine demonstrator engine program. The engine will be developed by General Electric in accordance with MIL-E-8593 as modified by the Army. The Army designation of the GE 12/TIAI engine is T700-GE-700.
DRIVE SYSTEM	• The drive system consists of nose, main, intermediate, and tail rotor gear boxes with associated shafting. • The main gear box combines the output of the two T700-GE-700 engines with a 120 percent rating of the combined output of the engines at 4000 feet, 95° F conditions. • The system will incorporate the maximum degree of damage tolerance practical. All gear boxes will be capable of 30 minute operation at the power required for cruise flight, following total loss of the lubrication subsystem.
COMMUNICATION SYSTEM	• The communication system will consist of the following equipment with retransmission capability between any two radios: VHF-FM radio set (30.0 to 79.95 MHz) – Clear and secure voice communication UHF-AM radio set (225.0 to 399.5 MHz) – Clear and secure voice communication VHF-AM radio set (116.0 to 149.975 MHz) – Clear voice communication • The system also provides aircraft intercommunication and serves as a data link with the tactical fire direction system and consists of the following equipment: AN/ARC-114 radio set — C-6533 control unit AN/ARC-115 radio set — TSEC/KY-28 voice security set AN/ARC-116 radio set
NAVIGATION SYSTEM	• The navigation system will provide for enroute and terminal navigation under visual meteorological conditions (VMC) and instrument meteorological conditions (IMC) with single ship instrument flight capability, at altitudes that insure terrain clearance, and single ship instrument approaches to landing at terminal areas equipped with landing approach aids. The system will include the following: LORAN navigation system providing continuous digital readout of present position in universal transverse mercator (UTM) coordinates and distance to selected destination point. It will also provide information to maintain a selected course to destination. An automatic direction finder set AN/ARM-89. VHF/FM homing set. A tactical landing system incorporating distance measuring to touch down. Complete provisions for civil airways navigation and instrument approach equipment, (i.e., VOR localizer, glide slope, and marker beacon).
IDENTIFICATION	• The identification system will provide identification friend or foe (IFF) with selectable identification feature (SIF) and secure mode operations. The system will include AN/APX-72 and computer KIT-1A/TSEC.
WEAPONS SYSTEM	• There will be two easily installed and removable pintle-mounted medium machine guns, one mounted on each side of the aircraft.

aircraft design. The characteristics being emphasized in the UTTAS development are energy absorbing structure, maintenance of livable space, elimination of missile hazards, emergency egress, and elimination of post-crash fire.

Figure AM–1 shows the YUH-60A configuration.

Key Operational Capability. The key operational capability of the UTTAS will be its low life-cycle cost with squad lift capacity. Inherent in this capability is design-to-cost and R&M improvements over the UH–1.

Opportunity Areas. UTTAS acquisition will provide the Army an aircraft that can accomplish missions throughout the range of temperature/altitude combinations where United States forces can reasonably be expected to operate. The UTTAS will satisfy requirements for an assault helicopter in the projected timeframe. In addition, it will have a higher degree of survivability in all intensities of conflict and provide a system that can be based, operated, and maintained in forward areas where it will be more responsive to the needs of the users. Consequently, the UTTAS will provide improvements in reliability, maintainability, vulnerability, survivability, performance, human factors, air transportability, availability, detectability, crashworthiness, and safety over the UH–1 series. It must be pointed out that R&D trends toward horsepower/pound, dollars/pound, etc., are not specifically involved in the UTTAS development. Except for the specific fuel consumption of the T700-GE-700 engines, the strategy of detailed trends and goals remains with the contractors. Specifically, that trend which permits the UTTAS to meet the requirement of the RFP and perform the primary mission is required.

In addition to the capabilities shown in table AM–I, it is noted that the UTTAS will have a 8000-lb external cargo hook capability that, generally speaking, will be usable in many ambient conditions. External lift capability is only limited by the maximum alternate gross weight of the UTTAS, which will be about 4000 lb above the mission gross weight. In other words, the UTTAS will be able to hover out of ground effects with external payloads of 4000 lb plus the 2640 lb of internal payload and mission fuel at sea level, 95°F conditions. Of course, fuel, troops, internal and external payload trade-offs can be made as long as center-of-gravity limits and maximum alternate gross weight limits are not exceeded. Maximum range without ferry tanks (using full internal fuel) is 2.3 hr at sea level standard day temperatures.

Figure AM–1. YUH-60A configuration.

Potential Problems. There are no major problems at this time and none are expected because of the following reasons. The UH-1 helicopter was designed in the early 1950s and was the first turbine-powered helicopter to see wide operational application. The UH-1 was a product of a specialized industry with technological breadth well below that of the rest of the aviation industry. Since that time, the helicopter industry has developed technological capabilities and breadth spanning the scope and disciplines of the aerospace technology and engineering field. Improvements incorporated into the UH-1 during the last 10 years in part reflect this maturity. These broad advances have set the stage for major potential advances in effectiveness and efficiencies for the next generation of helicopters.

Current and Planned Activities. Figure AM–2 shows the present program schedule for the UTTAS.

Trade-off studies performed by the airframe contractors during engineering development included a Central Integrated Checkout System (CICS) diagnostic system, aircrew armor, personnel/cargo handling subsystem, instrumentation, survivability/vulnerability, aircraft fault warning subsystem, noise control program, crew station geometry, and a producibility study.

The UTTAS development program, as shown in figure AM–2, consists of two phases, Basic Engineering Development (BED) and Maturity (MAT). The BED phase was the competitive portion of the program, and the MAT phase is conducted with the selected design. During the competitive phase, both Sikorsky and Boeing-Vertol built three flight-test prototypes, one Ground Test Vehicle (GTV) and one Static Test Article (STA). The aircraft were used by the competing contractors for demonstration and airworthiness qualification in preparation for the competitive testing. The three aircraft were delivered for the competitive test, but the GTV and STA were retained by the contractors for continued qualification and development under Army supervision.

The BED phase was divided into three periods: (1) contract award to first flight, (2) first flight to delivery of prototypes for evaluation, and (3) the Government Competitive Test (GCT).

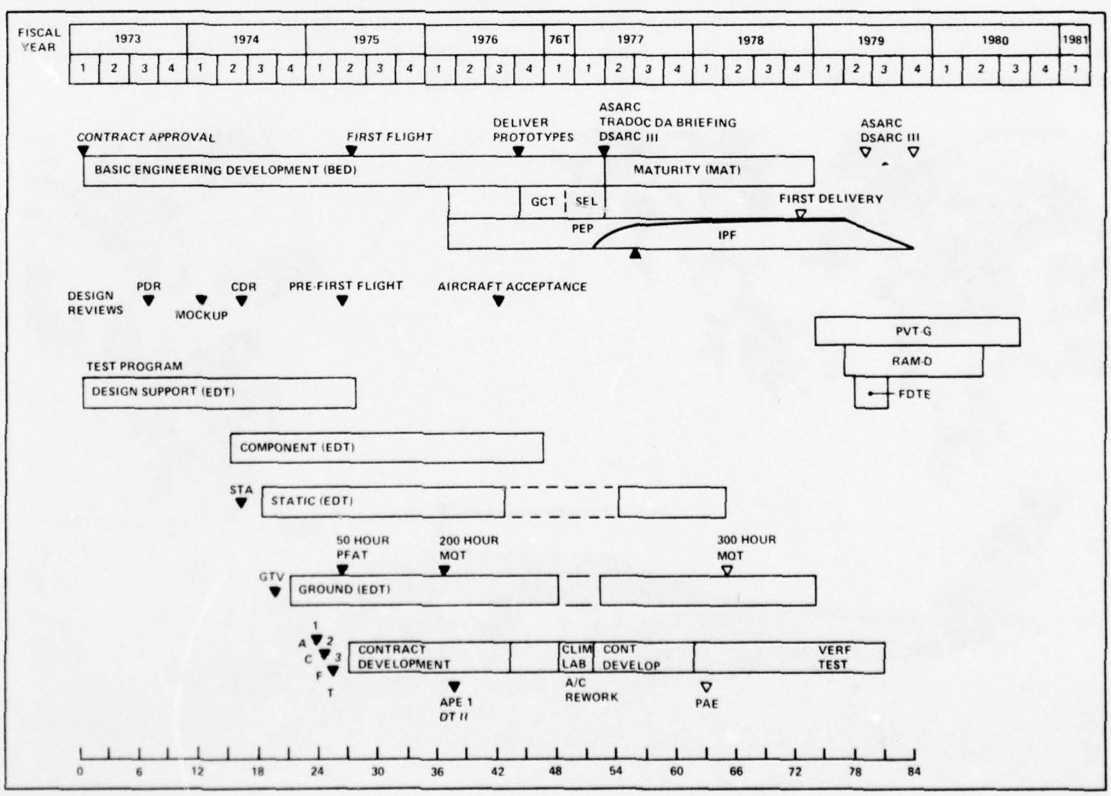


Figure AM–2. UTTAS program schedule.

At the conclusion of the BED phase, adequate development and operational testing was accomplished to assist in the selection of the winning design and allow the award of a limited production contract. The following DT/OT tests were completed on each of the contractors' designs:

- 480 hr of contractor flight (EDT) tests
- 20 hr of Government flight (DTII) tests
- 1220 hr of contractor GTV (EDT) testing
- 715 hr of Government flight (DT/OTII) tests
- Climatic Laboratory Survey
- 300 hr MQT on dynamic components

Table AM–K is a list of subsystem and dynamic component reliability test hours that are scheduled during development.

During the MAT phase (23 months) the selected contractor and the Army will complete the UTTAS Airworthiness Qualification Program (AQP) and correct any deficiencies/shortcomings encountered during the GCT. The AQP concludes with the Airworthiness and Flight Characteristics (A&FC) test, and RAM and Suitability Test. In addition, the selected contractor is required to achieve a 1200-hr MQT on dynamic components prior to delivery of the first limited production UTTAS, and complete the extensive reliability and maintainability programs to effect compliance with the MN requirements.

TABLE AM–K
UTTAS RELIABILITY TEST

COMPONENT	TOTAL TEST HOURS	GTV AND FLIGHT TEST HOURS
• Main Transmission	8500	2500
• Engine Transmission	5500	2500
• Drive System Shafting	5500	2500
• Tail Rotor Intermediate and Right Angle Transmission	5500	2500
• Swashplate	8000	2500
• Rotating Main Rotor Controls	5500	2500
• Main Rotor Head	5500	2500
• Main Rotor Blades	5500	2500
• Tail Rotor Hub and Blades	5500	2500
• Main and Tail Rotor Control Actuators	4500	2500
• Flight Control, Hydraulic, and Electrical Subsystems Components	4500	2500

DTIII and OTIII tests will be performed on the initial production aircraft.

MEDIUM LIFT MISSION – CH-47D

General. The follow-on system for the current CH-47 fleet will be the CH-47 Modernized Medium Lift Helicopter (MLH) to be designated as the CH-47(D). This is essentially a major modernization effort and although, for convenience in concept categorization, it is presented under the heading of developing systems, it should not be considered in the same light as a new development project such as the UTTAS and AAH.

Current System. The current CH-47 Chinook Medium Lift Helicopter (MLH) was designed as a transport helicopter with these missions: artillery movement, missile transport, personnel movement, aircraft recovery, medical evacuation, transport of liquid and dry bulk cargo and other combat and combat service missions during day, night, and adverse weather conditions. The CH-47 has the capability of carrying cargo internally and/or externally depending on cargo configuration. It was developed in the late 1950s using technology of that era. The CH-47A with a 9600 lb lift capability, was the first aircraft to be delivered in the 1962-1967 time frame. Later the CH-47B, which incorporated improvements in speed and payload capabilities, was procured as an interim model. It provided an external lift capability of only 9400 lb. This model was followed by the CH-47C which satisfied the Army's requirement for 15,000 lb MLH external payload.

The current fleet has four primary inadequacies: systems operating costs are a support burden on critical Army resources; A and B series aircraft, as currently configured, are approaching planned retirement; the A and B series do not meet the 15,000 lb lift requirement needed to provide air-mobility to artillery and engineer equipment; and the reliability, availability, maintainability, safety and survivability

features of all existing CH-47s are inadequate and need to be upgraded to current standards.

Contingency Analysis. The need for MLH capability was recognized to continue through the 1980s. To sustain this capability, it was determined that a modernization and/or procurement program would be necessary.

In 1968, an aircraft life expectancy of 10-15 years was used for planning. Recognizing the long lead time necessary to bring a replacement system on line, a new project called the Light Tactical Transport Aircraft System (LTTAS) was initiated. This project was subsequently terminated by the Department of the Army when it was determined that the CH-47C lift capability of 15,000 lb at 4000 ft 95° hover-out-of-ground effect with 200-500 fpm rate of climb satisfied the lower band of the LTTAS requirement. During the entire period between 1962 and 1974, the Army continued with R&D efforts to improve its medium lift helicopter capability. These efforts included numerous studies and technical reports by schools, research corporations, and aircraft manufacturers, that had a direct effect on the medium lift helicopter. In 1969, the Army initiated a two-phased program with Boeing-Vertol; the program was designed to allow the user and technical community to assess advanced transport helicopter capabilities and to provide a sound basis for future military needs. This program resulted in the CH-47-347 proposal in late 1971 which far exceeded Army lift requirements and was subsequently rejected.

The advances in technology and concepts which could satisfy deficiencies could not be rejected and led to a sequential review, by the Army, of all technology which could be applied to the existing CH-47. This review began with 31 proposed modifications and with some redirected R&D efforts was reduced to 15 and finally stabilized at 7 component/system changes. This effort resulted in the Concept Formulation Package which supports the CH-47 Modernization Program as opposed to a new procurement – the most cost effective means to sustain the Army's medium lift helicopter fleet. It was recommended that the entire fleet be modernized.

The CH-47 Modernization Program which was subsequently approved by the Army to sustain the MLH mission capability is primarily an engineering effort for the design and integration of seven improved components or systems into the modernized aircraft. Figure AM–3 identifies the areas of systems improvements to be accomplished on the modernized fleet

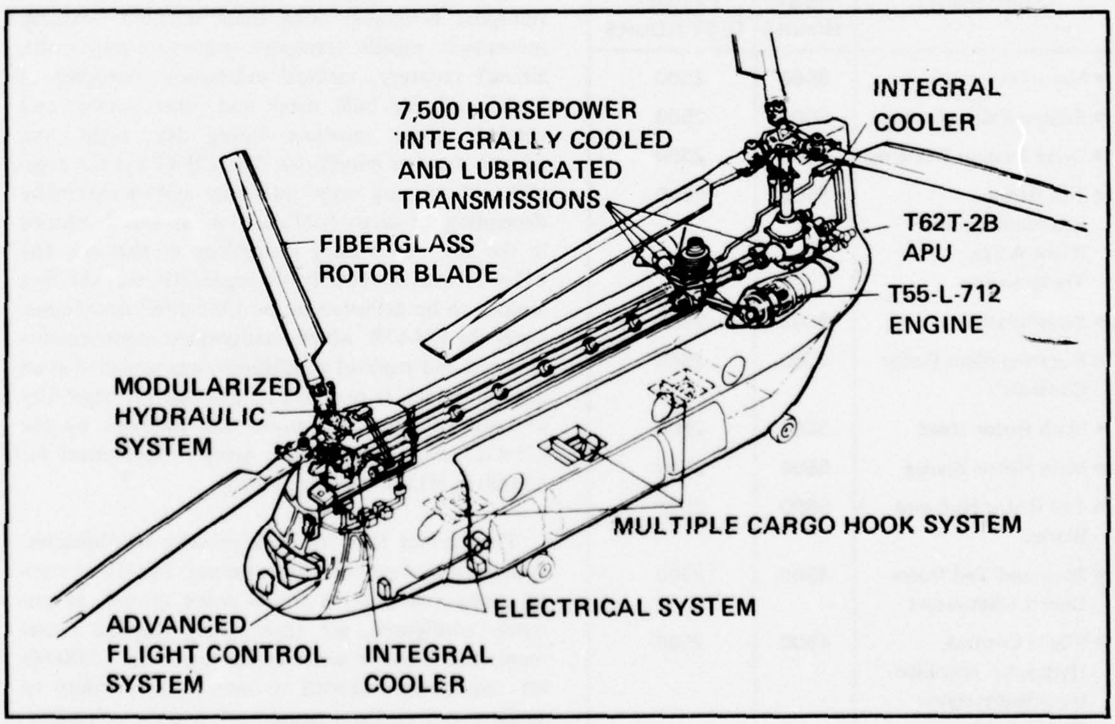


Figure AM–3. CH-47 modernization improved systems.

and table AM–L briefly describes each of these components and highlights some of the benefits derived from each.

The CH-47 Modernization Program is an example of improving existing assets to achieve maximum return on investment.

TABLE AM–L
CH-47 MODERNIZATION COMPONENTS

FIBERGLASS ROTOR BLADE	• The new fiberglass rotor blade is a fail safe redundant structure with space for deicing capability; will be corrosion resistant, will have reduced vulnerability; and is expected to have a significantly improved service life. The fiberglass blade will provide a solution to every major problem existing with metal blades today.
TRANSMISSION/ DRIVE SYSTEM	• The CH-47 drive system will be redesigned to incorporate integral cooling and lubrication systems; better gear, bearing and case materials; and the 100% oil flow monitoring debris detection system. It will be uprated to 7500 horsepower. Reliability will be improved by increasing the size of internal components, and tuning the dynamic components. The system will be less vulnerable because of the elimination of cooling and lubrication lines on the forward, aft and combining transmissions.
HYDRAULIC SYSTEM	• The flight control and utility hydraulics systems will be modularized to: reduce lines, hoses and fittings; improve reliability; pressurized utility systems only when in use; integrate components; jam-proof the upper and lower flight control actuators; and provide minimum fluid leakage from remaining lines.
AUXILIARY POWER UNIT	• Auxiliary Power will be physically, electrically, and hydraulically separated from the auxiliary gear box and transmissions of the aircraft. The improved configuration will avoid the potential of a total power failure by using drive pads for the hydraulic and electrical systems on the gear box mounted to the power turbine.
ELECTRICAL SYSTEM	• The existing electrical system will be modified to increase power generation and transmission, improve reliability and reduce vulnerability. This change is based on the need to replace installed wiring, the increased electrical power required for improved avionics, aircraft survivability equipment and, if necessary, rotor blade deicing. It will separate the redundant AC and DC systems by placing the No. 1 on the right side of the aircraft and the No. 2 on the left. Wire bundle routing will be relocated to the inside of the aircraft.
ADVANCED FLIGHT CONTROL SYSTEM	• Future combat will require flight operations at low level and during period of limited visibility, including external cargo movement under instrument conditions. To date, several accidents have occurred during hover and confined-area operations. The AFCS, will provide increased control response and longterm trim hold through the addition of special hold features to the existing CH-47C Stability Augmentation System.
MULTI-CARGO HOOK LOAD SUSPENSION SYSTEM	• To increase external load stability two additional cargo hooks will be externally mounted at stations 260 and 420. This will increase forward flight speed for high-drag, low-density loads, such as containers and aircraft, and permit operations at the power limit of the aircraft.

Component Improvements. Under the modernization plan the improved components/systems will be incorporated into a rehabilitated airframe configuration. A key element of the program is the capability of the older CH-47 airframes to continue to operate through the 1990s. The strength of the current CH-47 airframe was verified on the CH-47A. Airframe fatigue stresses were determined to have an unlimited life. The complete tear down and detailed inspection of three CH-47s after 2700 flight hours and up to 4 years of combat service further confirmed the integrity of the airframe as did the fact that no CH-47 accidents are attributable to airframe failure. For the prototype program, one each CH-47A, B, and C model aircraft were provided the prime contractor for induction into the modernization program. Each of the three aircraft has been stripped of all electrical, hydraulic, and drive system components. The aircraft structures have been cleaned and washed. They will be upgraded to the latest CH-47C configuration to which the improved components/systems will be added, resulting in the YCH-47D prototypes.

Propulsion System. The standard engine currently used in the CH-47A and CH-47B Chinook helicopters is the T55-L-7C version which can produce 2850 hp. The demands of the Vietnam war introduced the requirement for a change in payload capability of the Chinook, resulting in another product improvement for both the airframe and engine. As a result of this dual thrust to improve the system, by the 1967-1968 time frame, the T55-L11 series engine was developed to power the CH-47C helicopter. The 3750-hp engine continues to be improved through the component improvement program (CIP).

Looking forward to the modernized Chinook, the current effort is to develop what is called the T55-L-712 engine. Development of this version of the T55 engine will be accomplished through modification programs and is a separate effort from the CH-47 RD&E development project. A new wide chord compressor blade configuration, the welded rotor, nozzles with improved cooling capability, an improved design T17 harness plus several other material changes will be included in the RAM-D engine. This engine is required and planned for conversion to coincide with the modernized CH-47 Chinook in the 1979-1980 time frame. The progression of the T55 series engines component improvement program as presently planned is as follows:

- T55-L7C – Standard version for CH-47A and a temporary engine for limited CH-47B/C aircraft.
- T55-L11A – Standard version for CH-47C aircraft.
- T55-L11A/B – Includes shot-peened third stage turbine.
- T55-L11ASA – Includes welded rotor assembly.
- T55-L11D – Includes wide chord compressor blades.
- T55-L712 – Ultimate version for the modernized aircraft (formerly the RAM-D version).

Performance Objectives. The CH-47 Modernization Program is designed to increase the life of the older CH-47A, B, and C aircraft while upgrading the performance of the A and B to meet the Required Operational Capability essential characteristics. The basic performance characteristics of the modernized aircraft are the same as those of the CH-47C in such areas as speed, endurance, number of troops carried, etc. Since it will retain its basic characteristics, there are few performance bands specified in the ROC, unlike development of a new/replacement aircraft alternative. The key performance goals are payload and reliability (see table AM–M for specific performance parameters). The payload is required to preserve medium lift transport capability for the support of engaged forces under environmental conditions up to 4000 ft/95°F. Reliability is critical to provide for the required uninterrupted distribution of tactical equipment and supplies at FEBA.

Key Operational Capabilities. The following are the key operational capabilities that will be realized

TABLE AM–M
CH-47 MODERNIZATION PERFORMANCE PARAMETERS

PERFORMANCE PARAMETER	OBJECTIVE
PAYLOAD	• 15,775 lbs
RADIUS	• 30 NM
RATE-OF-CLIMB	• 200-500 fpm
MAINTAINABILITY	• 17.66 MMH/FH
RELIABILITY	–
SYSTEM OPERATIONAL	• 1.4 MTBF
HARDWARE SYSTEM	• 3.0 MTBF
MISSION	• 49.5 MTBF

from the modernization system over the current systems:

- Improved capability to operate under night and adverse weather conditions.
- Provide for flight operations for low-level terrain flight tactics.
- Increased operational fleet lift capability of 15,000 lb at design conditions 4000 ft, 95°F, 30-nautical-mile mission.
- Double productivity with outsize loads and multi-delivery capability.
- Stable external load transport.
- Improved stability and control in confined areas and other critical operations.
- Increased mission reliability through system and hardware reliability improvements. System operational reliability deals with the total malfunctions of an aircraft and is indicative of the actual maintenance hardware the aircraft imposes on the support environment. The hardware system reliability deals with the malfunctions attributable to the inherent design characteristics of a particular component.

Opportunity Areas. Looking at the total modernized aircraft in terms of indirect or noncosted returns, significant improvements are expected in the areas of reliability, availability, maintainability (RAM), safety, and vulnerability. Table AM–N is a matrix that represents the areas of expected indirect returns of the systems to be modernized. The following specific benefits for the U.S. Army are predicted:

- Reliability – 15 percent reduction in maintenance failure rates from 1.04/hr to 0.88/hr.
- Availability – 4.50 percent increase in inherent availability – from 84.20 percent to 87.97 percent.
- Maintainability – 24 percent reduction in maintenance manhours per flight hour. Reduction from 23.18 to 17.66 MMH/FH for total direct productive field maintenance. Reduction from 14.22 MMH/FH to 10.83 MMH/FH aviation unit maintenance.
- Safety – 14 fewer aircraft lost (15 years of operation).
- Productivity – 13.9 percent (Mid-East) and 47.6 percent (Europe) increase in ton-NM day.
- Vulnerability – 36 percent to 75 percent reduction in vulnerable area, depending on type weapon.

TABLE AM–N
EXPECTED SYSTEM IMPROVEMENTS

BENEFIT	ROTOR BLADE	DRIVE SYSTEM	HYD SYSTEM	ELECT SYSTEM	MULTI HOOK	AFCS	APU
RELIABILITY	•	•	•	•			•
AVAILABILITY	•	•	•	•			•
MAINTAINABILITY	•	•	•	•			•
SAFETY	•	•	•	•	•	•	•
VULNERABILITY	•	•	•	•			
PRODUCTIVITY	•	•			•	•	

In terms of direct investments, total life cycle cost savings (discounted) will be approximately $189.5 million. Using a 20-year retirement life, a constant fleet size and discounted dollars, a return on investment could be realized at the rate of 3.7 percent per year or 55.4 percent over 15 years.

Other benefits to be derived from the Modernization Program include:

- Extension of fleet life.
- Standardized configuration of all CH-47s.
- Maximum parts standardization.
- Reduced direct operating costs in the field.
- Increased mean-time-removal for transmissions on rotor blades.
- Continuity of service support for Army ground forces due to the termination of the Heavy Lift Helicopter Program.
- Improved assistance to the Army in peacetime military commercial construction tasks, recovery of downed aircraft, disaster relief, shipment of containerized military cargo, etc.

Potential Problems. There are no major problems at this time and none are expected. Technical risks are considered low because:

- The Modernization Program is applying available and proven technology resulting from previous development efforts with the advanced subsystems.
- The rotor blade design is complete.
- Advance development design is under way for the hydraulic and transmission systems.

- A similar cargo suspension system has been flight tested.
- A similar advanced flight control system is production qualified and operational on the Canadian Chinook.
- Accelerated RAM testing will ensure early maturation of the modernized components.

Minor problem areas may arise during the engineering development phase. Potential development and production problem areas will be addressed in the next annual update of this RDTE program if unexpected difficulties occur.

Current and Planned Activities. In April 1975, the initial contract phase of the modification effort was initiated with a procurement contract which authorized Boeing-Vertol to proceed with the necessary analysis and advance engineering to design the transmission and hydraulic system. A separate engineering development contract with Boeing-Vertol is in effect for the development of the fiberglass rotor blades.

In August 1975, the CH-47 Modernization Program was presented to ASARC II and on 16 October 1975 it was placed before DSARC II. The ASARC and DSARC decisions recommended approval to the Deputy Secretary of Defense (DEPSECDEF) for the modernization of all models of the current CH-47 fleet. The Deputy Secretary of Defense reviewed the DSARC II recommendations and authorized the Army to proceed into full-scale engineering development to develop one prototype each of the CH-47A, B, and C models. Contractor's proposal for engineering development for the three prototype aircraft was received in October 1975; contract award was effected in June 1976. This contract does not include production follow-on programs. After successful DT/OT testing of the prototypes, an initial production contract will be awarded to modernize the CH-47 fleet at the rate of three per month.

CARGO TRANSPORT MISSION

There are no cargo transport helicopter system development efforts under consideration by AVRADCOM R&D at this time.

FUTURE MOBILITY SYSTEMS

UTILITY MISSION

Although there are no AVRADCOM R&D efforts that directly relate to the future utility mission system, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed for a future utility system. A possible tilt-rotor configured utility aircraft is shown in figure AM–4. In addition, a Light Utility Helicopter (LUH) with performance compatible with that of the ASH is also needed to assume many of the missions associated with mobility, combat service support, and command, control, and communications. A description of the LUH is provided in table AM–O.

MEDIUM LIFT MISSION

There are no medium lift aircraft systems under consideration by AVRADCOM R&D as a replacement for the CH-47 Modernized Medium Lift Helicopter.

CARGO TRANSPORT MISSION SYSTEM

General. The Advanced Technology Components Development concept for a heavy lift helicopter (HLH) was terminated and there is not a current AVRADCOM R&D development effort in this area. However, the Materiel Need (MN) document for a heavy lift cargo transport system is still valid as well as a STOG-78 requirement.

The primary mission for a HLH would be the transport of containerized and unitized cargo in an aerial or surface port clearance operation, unloading and loading container ships, and recovery and evacuation of damaged equipment. An additional mission would be to provide air transport of equipment too heavy for the medium lift system. Figure AM–5 shows various loads up to 35 tons that would be applicable to the HLH mission requirement.

Vehicle Concept. Trade-off determinations based on the HLH MN document resulted in the selection of a tandem rotor helicopter concept. The configuration selected to demonstrate the advanced technology components is shown in figure AM–6.

Considerable development efforts will be required for an HLH to be capable of transporting loads in the 50-ton range. For such a payload, configurations such as shaft-driven, hot cycle, or other gas reaction drive types must be considered. The total installed power would be of the order of 50,000 shp, with a transmission capable of transmitting more than 2.5×10^6 ft-lb of torque. Another configuration that deserves consideration is a hybrid lighter-than-air aircraft composed of balloon and helicopter elements. This configuration integrates the controllable thrust vector of

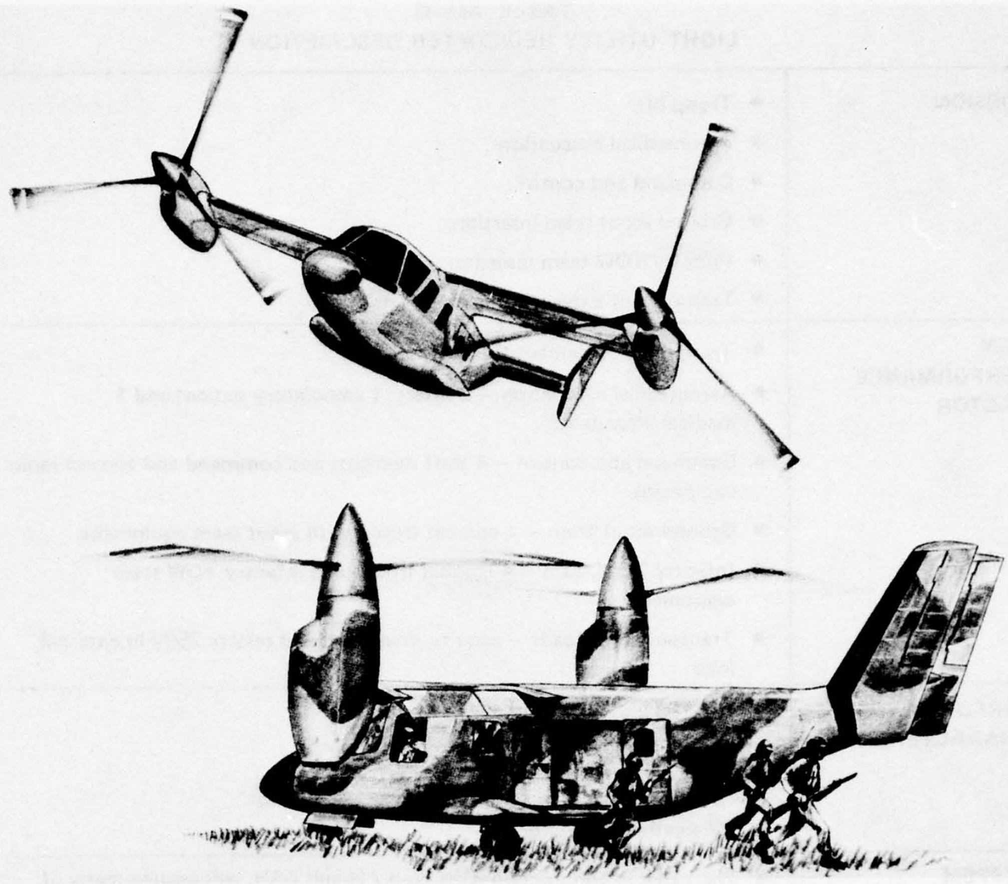


Figure AM–4. Possible tilt rotor version of future utility aircraft systems.

a rotary wing system with the lifting capability of a heavy lift balloon. Aerostatic lift may support the full aircraft weight and up to 50 percent of the design sling load while aerodynamic lift supports only the remaining 50 percent of the sling load. Because the aerodynamic lift is not required to support the vehicle weight, the "square cube law," which plagues large helicopter design, is no longer applicable. A possible configuration concept is shown in figure AM–7.

In addition to enhancing the deterrent capability of our general purpose forces, the HLH will have peacetime uses. It will be available to assist Government agencies with disaster relief in civilian communities and to provide support to the Nation's space effort. It is anticipated that there will be civilian applications for the HLH in the lumber and construction industries, as well as in the energy-related industries. An HLH should offer significant advantages to civilian industries involved in the construction and support of nuclear power plants, and petroleum acquisition and distribution facilities, particularly those offshore. In addition it may provide the only secure means of transporting the heavy (25 tons) recoverable cores of the many nuclear power plants that will be required to meet our energy requirements beyond 1980.

Salient Characteristics. The system description of an HLH capable of carrying 20-50 ton payloads is presented in table AM–P.

Planned Activity. Although the HLH program was terminated by Congressional direction on 26 September 1975, the Materiel Need document dated 10 May 1972 (ACN 2958) remains valid. Assets required to complete the program have been temporarily stored, thus future HLH efforts are primarily dependent on funding constraints.

TABLE AM–O
LIGHT UTILITY HELICOPTER DESCRIPTION

MISSION	• Troop lift. • Aeromedical evacuation. • Command and control. • Ground scout team insertion. • Infantry TOW team insertion. • Transport of external sling loads.
KEY PERFORMANCE FACTOR	• Troop lift – 6 combat troops. • Aeromedical evacuation – 2 litters, 1 ambulatory patient and 1 medical attendant. • Command and control – 4 staff members and command and control radio equipment. • Ground scout team – 4 combat troops with scout team equipment. • Infantry TOW team – 4 combat troops and infantry TOW team equipment. • Transport sling loads – acquire, transport, and release 2500 lb external load.
PERFORMANCE CHARACTERISTICS	• 120-150 knot airspeed. • 2.0 hr endurance. • 450 fpm VROC. • All weather capability.
SYSTEM APPLICATION	• The LUH, in conjunction with the LAH and ASH, will assume many of the present missions of the UH-1, OH-6, and OH-58.

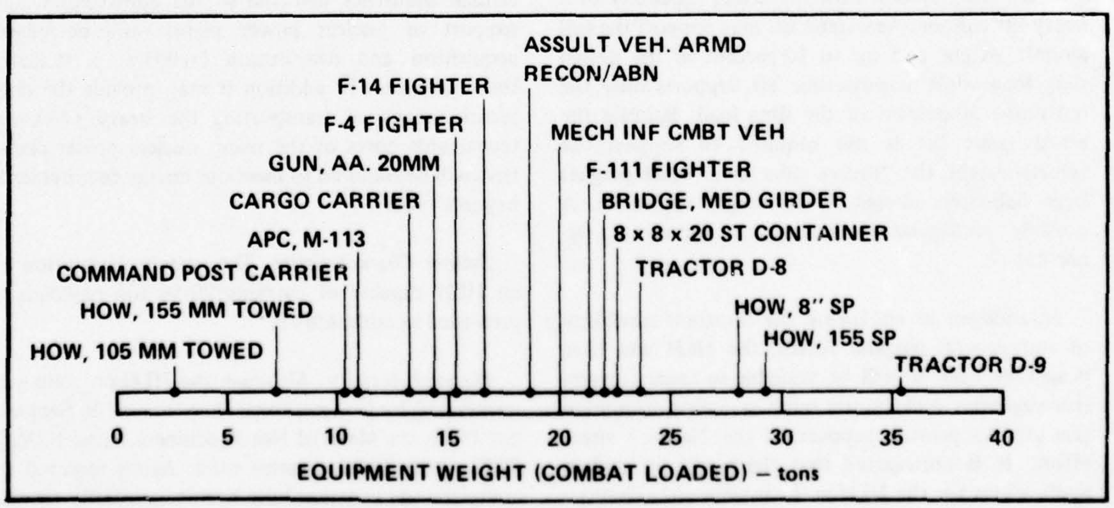


Figure AM–5. Payload capability of the HLH.

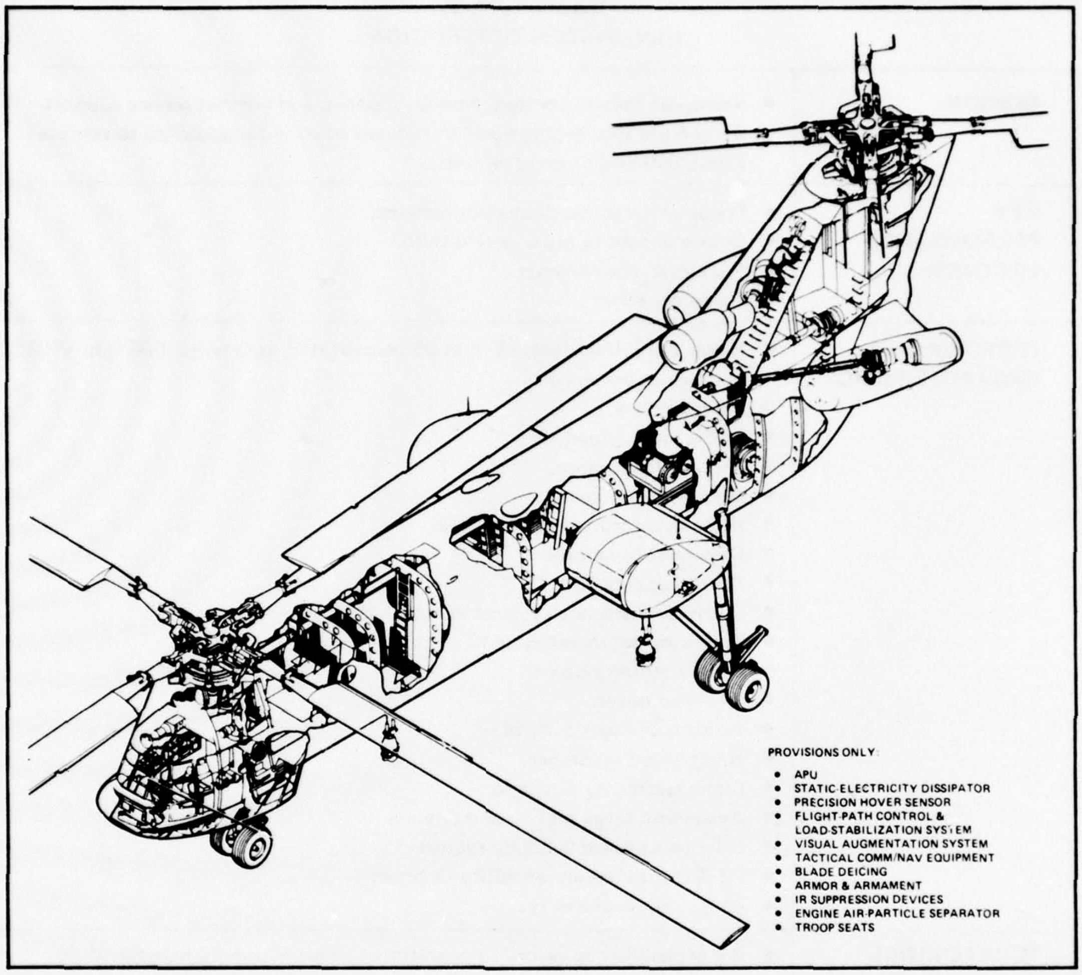


Figure AM–6. Advanced technology component projects of the HLH.

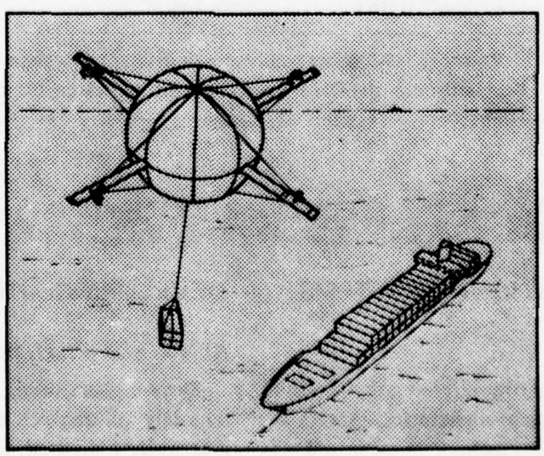


Figure AM–7. Lighter-than-air cargo transport concept.

TABLE AM–P
HLH SYSTEM DESCRIPTION

MISSION:	• Transport outsize combat, combat support, and combat service support items from ship to shore and to forward bases with capability to retrieve equipment and downed aircraft.
KEY PERFORMANCE FACTORS:	• Precision cargo handling requirements. • Empty weight to gross weight ratio. • Fuel load requirements. • Cargo capacity.
PERFORMANCE CHARACTERISTICS:	• Hover OGE 4000 feet, 95°F at 95 percent IRP, zero wind, 500 fpm VROC, at design gross weight. • 3-6 man crew. • 20-50 ton payload. • 2-4 hour endurance. • Mission Subsystems • IR countermeasures as required. • Day-night capability • Anti-icing capability • Electronics warfare systems as required. • Traffic management system. • Fault warning system. • Precision hover. • Automatic flight control. • Night vision assistance. • Static electricity dissipator. • Automatic cargo pickup and releases. • Dual point cargo handling system. • 90 percent mission reliability (2 hours). • 80 percent availability.
MAINTENANCE CHARACTERISTICS:	• 0.9 probability to resore to operational status within 30 minutes after failure. • 300-hour periodic inspection. • 1200-1500 hours between overhaul. • 3000-4500 hour retirement life.
SYSTEM APPLICATION:	• There is no comparable existing aviation system in operation at this time although the CH-54 performs limited cargo transport functions.

INTELLIGENCE SYSTEMS

CURRENT OPERATIONAL SYSTEMS

RSTA/D

The current RSTA/D Army aircraft are the light observation helicopter and the observation aircraft. A discussion of the LOH is presented in table AM–Q and of the OV-1D in table AM–R.

DEVELOPING INTELLIGENCE SYSTEMS

REMOTELY PILOTED VEHICLES

System Discussion. The potential of unmanned, remotely piloted vehicles for military application is practically unlimited. Extensive efforts on RPVs have been under way for many years, covering a wide

TABLE AM–Q
CURRENT LOH DESCRIPTION

GENERAL	• This aircraft is used in visual reconnaissance, aerial scouting, and command and control functions by brigade and lower units. The current aircraft are the Bell OH-58A and Hughes OH-6.
PRESENT CAPABILITIES	• For unarmed observation missions, the OH-58A has a 260-mile range, or 3.0 hr endurance at a takeoff gross weight of 2,760 lb. Armed with the XM-27EI weapon system and 2,000 rounds of ammunition, it can perform an armed scout mission with a range of 230 miles, take-off gross weight of 2,767 lb, with a subsequent reduction of endurance. It is light, agile, relatively easy to fly and maintain, and has good all-around visibility.
DEFICIENCIES AND SHORTCOMINGS	• The LOH is restricted to day and night visual and marginal visual flight conditions. It lacks navigational radios, instrumentation, and yaw stability for flight under instrument meteorological conditions (IMC). In the aerial scout role, its power and performance are inadequate. It has a distinctive noise signature, and needs improvements to lower its radar and IR signatures. It lacks vision-enhancing equipment; thus, target acquisition depends entirely on the ability to recognize the target, locate it by map coordinates, and transfer this information to the weapon crew.
FOLLOW-ON SYSTEM	• A product improvement program is being planned for the OH-58 to permit flight under instrument meteorological conditions and improved performance. For the high threat environment, the LOH is programmed to be replaced by the RPV.

TABLE AM–R
CURRENT OBSERVATION AIRCRAFT DESCRIPTION

GENERAL	• The OV-1D STOL airplane is the current Army observation aircraft.
PRESENT CAPABILITIES	• The OV-1D is capable of performing either IR reconnaissance or side-looking airborne radar (SLAR) missions. The SLAR and IR pods are interchangeable, providing quick-change mission adaptability. The aircraft can perform photographic and visual reconnaissance missions, has a 180-knot cruise speed, and an endurance of just under 2 hr. With external fuel tanks, ferry range exceeds 1,100 nautical miles. It has good short-field performance and can be operated from unimproved runways or dirt fields.
DEFICIENCIES AND SHORTCOMINGS	• Because of its mission and method of employment, the survivability of the OV-1D is inadequate. It lacks adequate antiradar and antiinfrared electronic countermeasures. It lacks terrain-avoidance equipment for nap-of-the-earth flight. A higher dash speed is required for increased survivability during mission accomplishment. In addition, a greater endurance is required to increase mission payoff. Greater reliability of both the aircraft and avionics sensor package would be highly desirable.
FOLLOW-ON SYSTEM	• The OV-1D is programmed to be replaced by the OV-X.

range of applications and missions. It is only recently, however, that both the need and the technological capability for RPVs have coalesced to the point that the development of these systems has become imperative.

The primary driving force behind the present Army program is the highly sophisticated threat posed to any airmobile system used in a modern battlefield, as well as the danger a forward observer/designator faces in a modern battlefield. The threats to aircraft performing surveillance, reconnaissance, target acquisition, damage assessment and similar roles have increased markedly because of the existing and projected ground-to-air guided missiles, as well as the multimode acquisition and tracking quad-23 anti-aircraft gun system. The high threat posed by these weapons tends to deny airspace to the Army and severely limit its ability to obtain battlefield information as well as its ability to locate and designate targets precisely. Such limitations could adversely affect the operations of the battlefield commanders.

One logical counter to this threat is the use of small unmanned air vehicles (mini-RPV), designed to be produced and operated at the lowest cost possible. By reducing the observables (visual, acoustic, IR emission, and radar cross section) such mini-RPVs could penetrate sufficiently close to selected areas within and beyond the FEBA to be effective. Sensors, cameras, and designators, mounted on the RPVs, can be used to transmit real-time information for surveillance and target acquisition, perform reconnaissance, and designate targets. Without a man in the aircraft, the size and cost of the aircraft can be reduced, and missions can be performed in very high threat environments without concern as to the possible loss of life of the aircrew. If the cost can be made low enough, the RPVs may be considered expendable.

The predecessor programs to the present Army mini-RPV work consisted of a series of exploratory tests of mini-RPVs conducted under the sponsorship of DARPA. In these studies, model airplane radio control technology was applied and growth versions were constructed and tested. It was shown to be technically feasible to operate motion picture cameras, transmit TV pictures, and designate from small aircraft (wingspans of 10 to 15 ft, speeds up to 100 mph). Following this work, the Army (ECOM) with DARPA support conducted the RPAODS (Remotely Piloted Aerial Observation/Designation System) program. That program explored the low cost mini-RPV approach in more depth. A series of available aircraft was procured, as well as a range of small, lightweight sensors. Testing was accomplished at an RPV test range set up at Ft. Huachuca, Arizona. Studies on the vulnerability, data link, and sensor capability were conducted. The overall results tended to verify the earlier conclusions that mini-RPV could perform several of the surveillance and target acquisition roles.

Subsequent to the RPAODS program DARCOM assigned responsibility for the management of all Army RPV development to AVRADCOM. In February 1974 AVRADCOM created the RPV Weapons Systems Manager Office.

On the larger scale, the U.S. Air Force has had a broad-ranging RPV program, which has included the large Firebee-type drones, the large Compass Cope high-altitude, long-duration system, as well as work funded by DARPA in the mini-RPV area such as the Lockheed AEQUARE.

Other high-performance RPV systems besides the Firebee include a modified version of the Northrop MQM-74, the Belgian Epervier, and the Canadian AN/USD-501. All of these high-speed drones are, or can be, configured to carry out some of the missions discussed; however, their cost may be higher, loiter time lower, and observables higher. Derivatives of such drones could be useful for selected missions.

The range of possible aircraft systems to fulfill the need for a low-cost RPV includes modifications to existing large drones, through modified model airplane technology. The history of drones has shown that the recovery of the aircraft is a most difficult problem. Earlier Army experience with the SD–1 to SD–5 drones indicated a very low mission completion rate, primarily because of recovery problems (mainly crash damage). Likewise, the Air Force did not get good effectiveness from their drones until they went to the Mid-Air Recovery System (MARS). In the MARS system, a parachute is released at flight termination, and a helicopter snatches the parachute and lowers the RPV to the ground. Thus, because of the troubled recovery history, many of the possible aircraft systems will emphasize the recovery phase of the system.

Another technological gap (and, hence, technological challenge) is the absence of a secure data link capable of sending real-time or near-real-time video information, as well as target, vehicle status, and navigation information. The propulsion for the RPVs

is critical because no engine developments have been undertaken for mini-RPVs and total dependency has been placed on using engines derived from commercial engines such as "Go-Kart" or modified model airplane engines. In the slightly larger categories of RPVs, the loiter time is a direct function of the type of propulsion used. If loiter time is to be increased, then propulsion changes will be necessary.

The method of field operation of RPVs by battlefield units is unknown. Except for the SD–1 through SD–5 drone series, the Army has little experience in RPVs under field conditions. The best philosophy for integrating aircraft, ground control, launch and retrieval, support, training and maintenance procedures are, as yet, undetermined. A means for controlling several RPVs simultaneously must also be established before full exploitation of RPVs can be ensured. The need to operate at night and under a wide range of weather conditions poses a whole host of technical questions, including effects on recovery, the navigation system, and the on-board sensors.

The primary missions for the RPVs appear, at this time, to be those related to information and designation. These roles include reconnaissance, surveillance, target location and identification, and target designation. Such missions will ultimately need to be carried out under night and all-weather flight conditions.

Other potential missions include target destruction by Kamikaze/strike tactics, jamming, decoys of all types, damage assessment, mapping, mine and REMBASS placement, and chaff, leaflet or chemical dispensing.

In many cases, a given RPV will be expected to handle a variety of these missions. Because of the diversity in missions, however, the needs for payload, duration, response time, and agility may require a few distinct sizes and types of RPVs to cover the spectrum adequately.

Three potential technical problems that apply to all RPV systems are indicated here. More specific problems are indicated in subsequent sections. The critical problems are:

- Jam resistant data link
- Engines and propulsion
- Recovery

The discussion here will be limited to the jam resistant data link, since the latter two items are discussed under the AQUILA program in the next section.

The jam resistant data link is considered the most critical technological problem in the deployment of RPVs in a combat environment. The ability to control the vehicles and to receive their transmitted data is vital to the success of the RPV concept. If the systems are jammed, the RPVs are useless. Such systems must be compatible with the military communications network and must fit into the overall frequency allocation system. Because the jam resistant systems for TV down link require considerable bandwidth, they pose special problems on frequency allocation. The frequencies that may be available are expected to be in J-band. However, at high frequencies (10-15 GHz) it may be difficult to develop the solid-state amplifiers planned for present mini-RPV systems. Since small size, low weight, low power, and reliability are all predicated on solid-state LSI techniques, the whole concept of secure data links in J-band may present a formidable problem.

One use of RPVs was demonstrated on 3 October 1975 when an RPV was used as an airborne laser platform to designate a tank during the CLGP (Cannon Launched Guided Projectile) demonstration. One laser guided artillery round was fired and scored a direct hit on an M-48 tank at a range of 8 miles.

In September and October 1975, MASSTER (now TRADOC Combined Arms Test Activity) conducted simulated RPV missions by mounting a Westinghouse Blue Spot TV sensor system in a U-1A (Otter) aircraft and flying reconnaissance missions during field exercises of an Armored Division. The direction of the entire operation was based on information displayed on a video monitor in a controlling ground station. Effective detection, recognition and tracking of trucks, tanks, helicopters, and other vehicles resulted.

In August 1975, an RPV was flown against radar controlled anti-aircraft guns at Eglin AFB. The RPV was detected and tracked under favorable conditions but no hits were scored during live firing.

Communication jamming was conducted from a mini-RPV during flight tests at Ft. Huachuca, Arizona, in November 1976. These flight tests demonstrated that it is feasible to jam ground-to-ground communications using a low power jammer carried by a mini-RPV.

These events demonstrate that RPVs can be effective in their assigned roles.

AQUILA PROGRAM

Description of System. Because of the lack of hands-on experience with RPVs, the Army was unable either to write an ROC document or to initiate normal, full-scale development of an RPV system. The combat developer not only needed experience operating the RPV but also a better understanding of how a full RPV system operated. This understanding is essential for the combat developer to determine the Organizational and Operational (O&O) concepts. The material developer had experimented with available experimental RPV hardware and had analyzed potential performance; however, the developer also lacked RPV systems experience. This experience is essential as an input to the ROC and Concept Formulation Package.

To overcome these deficiencies, a new technique and program were conceived, whereby a small number of representative RPV systems would be developed to demonstrate a range of RPV capabilities and complexities. The material developer would gain experience and data in developing and procuring RPV systems and the combat developer would gain hands-on experience with representative RPV systems. The system operational characteristics were based upon an informal letter requirement (little "r") rather than a formal approved ROC (big "R"). To keep costs reasonable, technical characteristics were based on state of the art; commercial off-the-shelf technology and hardware were used whenever feasible. Selected operational characteristics for this program, now called AQUILA (Latin for eagle), are:

- Launch and recovery in an unimproved area
- Range 15 to 20 km
- Minimum man-in-loop
- Map plotting board
- Real-time display
- Instant replay
- Video recorder
- Preprogrammable flight paths
- Operator override

The military designation XMQM–105 has been assigned to the AQUILA mini-RPV.

The AQUILA RPV System Technology Demonstrator (STD) consists of an RPV, Ground Control Station (GCS), launcher, recovery system and associated ground support equipment. The RPV (figure AM–8) is an all-wing design, 6-ft long, with a wing span of 12.3 ft; it is powered by an 11 hp single cylinder "go-kart" engine driving a pusher propeller. Interchangeable payloads are mounted in the nose. The structure is made of Kevlar for low weight and low radar reflectivity.

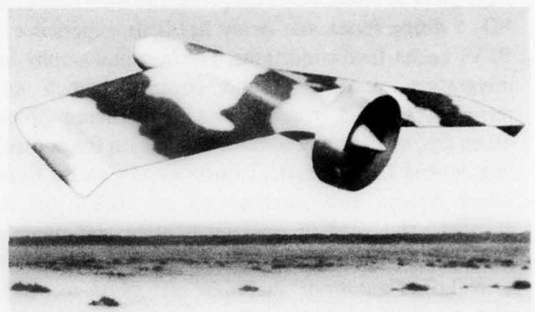


Figure AM–8. AQUILA RPV.

Control is exercised via data link from a GCS housed in a modified S-280 mobile shelter. The GCS contains separate video monitors and control panels for the RPV operator and the sensor operator, a computer, position plotters, radar antenna, and appropriate controls and displays. The data link provides for transmission of the TV video signal to the GCS, a command and control uplink, and telemetry down-link. An on-board autopilot system and GCS provide preprogrammable flight path control, operator override, and correction capability in both visual and non-visual line of sight operation.

The RPV is launched from a truck-mounted pneumatic catapult launcher. It is recovered by capture in a vertical arresting net from which it falls into a horizontal net. The RPV is guided to the center of the vertical arresting net by monitoring the glide path via a TV camera and making manual course corrections.

The overall system is illustrated in figure AM–9. Salient characteristics are summarized in table AM–S.

The AQUILA program was formulated in five phases corresponding to five different sensor packages. These progress from a relatively simple unstabilized TV sensor to more complex systems which include a panoramic camera, stabilized TV, and a laser designator. Phases of the AQUILA program that

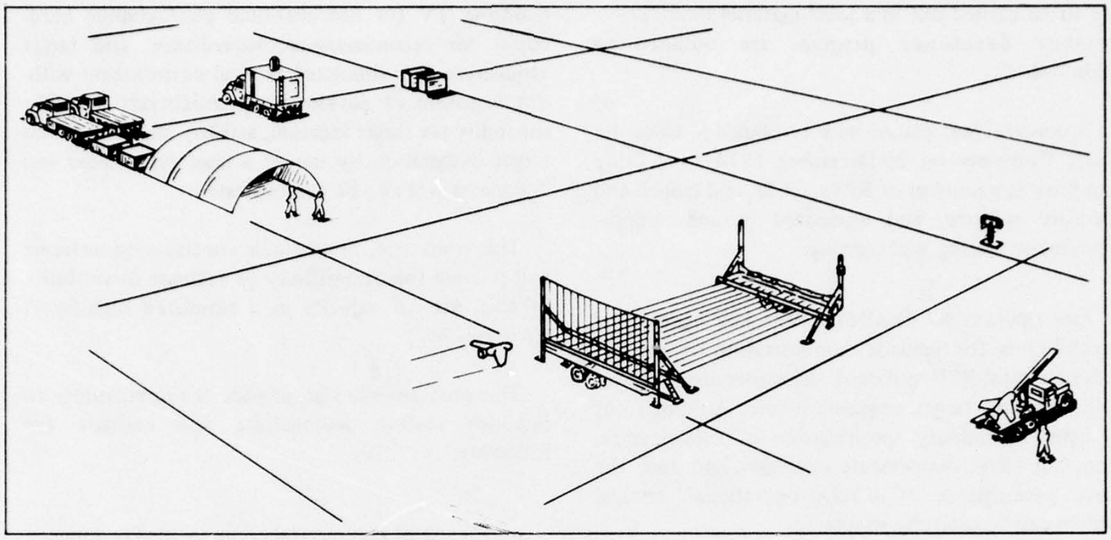


Figure AM–9. AQUILA system.

TABLE AM–S
SALIENT CHARACTERISTICS OF AQUILA

MISSION	• To demonstrate capability of a small, unmanned, remotely piloted aerial vehicle system to find, identify, locate, designate (with laser), and adjust artillery fire on enemy targets.
KEY PERFORMANCE FACTOR	• Within cost and time constraints, to demonstrate RPV system technology realistically.
PERFORMANCE CHARACTERISTICS	• Cruise (band): 50 to 90 kt • Gross wt. (max): 146 lb • Payload (min): 37 lb • Endurance (min): 3 hr • Minimum observables • Stable autopilot • Winds: 20 kt, gust to 35 kt • Common launch and recovery system • Common ground control system
MAINTENANCE CHARACTERISTICS	• Unit maintenance by operators • Support maintenance by contractor • Modular removal/replacement • Pre-launch go/no-go checkout • 15 launches per RPV with average 1.0 hr flight

are to be carried out in a joint materiel developer – combat developer program are outlined in table AM–T.

A contract was placed with Lockheed Missiles and Space Company on 20 December 1974 to develop and provide a number of RPVs, GCSs, and launch and recovery systems, and associated ground support equipment, testing, and training.

Key Operational Capability. The key operational capability is the realistic demonstration of a representative mini-RPV system in the reconnaissance, surveillance, and target acquisition role. Although not designed to military specifications of shock, vibration, humidity, temperature extremes, and dust, the basic performance of a fully operational, tactical system can be carefully simulated.

Opportunity Areas. AQUILA will demonstrate the abilities of an unmanned aircraft system to provide real-time TV (or near-real-time photographic hardcopy) for reconnaissance, surveillance, and target acquisition in a simulated tactical environment without exposure of personnel to antiaircraft fire. The capability for target location, artillery adjustment and target designation by use of a laser rangefinder and designator will also be demonstrated.

The small size, nonmetallic construction airframe will provide the opportunity to evaluate survivability of this class of vehicles in a simulated high-threat environment.

The program will also provide the opportunity to establish and/or demonstrate and evaluate the following:

- The use of commercial components (as opposed to full military aircraft specifications) with realistic evaluation in a simulated operational environment.

TABLE AM–T
AQUILA PROGRAM PHASES

PHASE I – TV SURVEILLANCE	• Ground station with: Position display or plotting board compatible with 1:50,000 and 1:100,000 scale tactical maps. Air data and condition displays. Auto pilot override. • Aircraft and sensor system with: Common airframe and engine. Interchangeable sensor subsystem. Unstabilized, steerable TV. Adjustable field of view. • Launch and recovery subsystem with minimum length launch and recovery. • Minimum GSE and system checkout.
PHASE II – PHOTO RECONNAISSANCE	• Aircraft with sensor system identical to Phase I with addition of a 35 mm panoramic camera.
PHASE III – TARGET ACQUISITION	• Aircraft with sensor system identical to Phase I except TV is stabilized to 0.05 mrad rms.
PHASE IV – TARGET LOCATION/ ARTILLERY ADJUSTMENT	• Aircraft with sensor system identical to Phase III with the addition of a laser rangefinder and computer in the ground control station to determine target location within 100 meters CEP.
PHASE V – LASER DESIGNATION	• Aircraft with sensor system identical to Phase IV. Laser designator compatible with terminally guided weapons.

- Maximum use of autopilot and preprogrammed flight as compared to man-in-the-loop operation.
- Techniques for launch and recovery in unimproved areas.
- Use of a way point, ground track navigation system.
- Target location and RPV control by an Analytical Photogrammetrical Position System (APPS) in a side-by-side experiment.
- Required military operator skill levels using Army hands-on operation.
- Realistic statistics and projections of RPV reliability and maintainability (RAM) requirements.

Progress/Problems. Flight testing began in December 1975. Problems arose early in the test program that led to the loss of several RPVs and to growth increases in program cost. Flight test operations were suspended from May 1976 to 10 August 1976 for the correction of deficiencies and the implementation of a program to improve system reliability. Substantial design changes and supporting system testing were incorporated during the stand down period.

Flight test operations were resumed in late August 1976. In September 1976, following the loss of an RPV during recovery operation, the arresting hook recovery technique was replaced by a vertical net recovery method. The arresting hook technique had proved to be operationally complex and intolerant of variable field conditions. From early October 1976 through 10 May 1977, 30 consecutive RPV flights were conducted without aircraft loss, bringing total flight time to over 28 hr. Waypoint navigation, semiautomatic recovery, 20 km ranges, aircraft performance, dead reckoning flight, and search, loiter and orbital flight patterns have been demonstrated. System launch, flight mission operation, and vehicle recovery by trained Army personnel have been demonstrated.

In September 1976 a U-1 (Otter) aircraft was made available for installation of AQUILA sensor systems for manned aircraft flight tests. In these manned aircraft tests the sensor systems are controlled from an AQUILA GCS. Otter/sensor flight tests were conducted from October 1976 through April 1977 by Electronic Proving Ground personnel and in support of the AQUILA program provided checkout of unstabilized sensors, stabilized sensors and computation software, and training of Army RPV crews.

Problems encountered in early tests were typical developmental problems compounded by the risk of putting developmental hardware into a field environment.

The currently available engines were developed for commercial ground applications. They are heavy and noisy, have high vibration levels and fuel consumption, lack auxiliary power drives, and have not been exposed to flight operations or qualifications. A significant 6.2 effort has been initiated to evaluate and modify such engines and to develop associated propellers, fuel systems, and generator/alternators.

RPV recovery systems have been beset with problems. Parachute recovery increases weight, size, and complexity of the RPV and is susceptible to damage. The helicopter aerial recovery technique is complex in addition to requiring dedicated recovery aircraft. The arresting hook technique originally used in the AQUILA program was complex and oversensitive to changing field conditions as might be expected in Army applications. Net recovery techniques, although employed successfully in the AQUILA STD Program and other limited efforts, may limit the tactical scenario because of the cleared site area requirements for recovery. An exploratory development effort was initiated in 1976 to study and evaluate RPV recovery systems.

As happens in most air vehicle development programs, the AQUILA RPV encountered growth in weight, complexity, and cost as the development progressed. Weight, complexity, and cost are crucial factors in the type of employment envisioned for mini-RPV systems. A 6.2 program was initiated in June 1976 that will investigate RPV weight and cost reduction techniques and evaluate the application of new manufacturing processes, such as spacewind, to the fabrication of mini-RPV flight vehicles.

Data link performance and reliability have been problems in the AQUILA RPV-STD Program as well as in earlier RPV programs. Data link operation is dependent on line-of-site contact and on location and performance of the antennas as well as the reliability of the equipment. Many design changes have been experienced in the AQUILA data link and antenna subsystems as the system has progressed through

development testing. Concern about data link performance persists. The operational data link will be subject to jamming. Techniques to prevent jamming are being developed for mini-RPV applications.

Survivability is a major concern. Small radar, visual, aural and infrared signatures are inherent in a mini-RPV and good design practice will minimize these signatures. The test at Eglin AFB, mentioned in an earlier paragraph, provided encouragement that the RPV can survive in a hostile environment. Radar cross-section (RCS) tests of an AQUILA RPV were conducted by Lockheed in 1976 and further RCS tests on an AQUILA RPV will be conducted in 1977 at Holloman AFB. A 6.2 effort was initiated in May 1977 for the design, test, and evaluation of low noise level propellers for mini-RPVs.

System and component reliability proved to be a problem in the early testing in the AQUILA program. As mentioned earlier, it was necessary to retreat from flight testing and develop a reliability improvement program that introduced more adequate subsystem and system level testing to mature the design. A 6.2 effort was initiated in January 1977 to design and test a family of servoactuators specifically designed for mini-RPV application. In addition, the AQUILA RPV-STD Program will result in an accumulation of reliability data for RPV application from its substantial and real environment test program.

Current and Planned Activities. The contract with Lockheed Missiles and Space Company for the design, development, testing, and maintenance of the AQUILA RPV System Technology Demonstrator and training of Army personnel is in its third year. Substantial changes in the program have occurred as a result of problems encountered and subsequent cost increases. To offset cost increases, the number of complete systems to be delivered to the Army was reduced. Currently, the contract will provide 14 RPVs, 25 sensor packages, 2 ground control stations, 2 launchers, 2 recovery systems and associated support equipment and spares. Flight testing began in December 1975, was suspended from 1 May 1976 through 10 August 1976 and resumed in late August 1976. Contractor testing was completed by July 1977 for turnover to joint DARCOM-TRADOC hands-on test evaluation. Army testing is to be completed in December 1977.

Successful completion of the AQUILA program will lead to the preparation of a ROC to be submitted to DA for approval in March 1978. Full scale development would then be initiated leading to an IOC for a tactical system in 1983.

Remaining AQUILA assets are planned to be used to provide airborne platforms to demonstrate advanced hardware and missions. These include day-night and all-weather capability, anti-jam data link, multi-RPV control, jammer, relay, alternative recovery concepts, and survivability concepts. A supporting technology program is described in later chapters.

FUTURE INTELLIGENCE SYSTEMS

GENERAL

An RSTA/D system is required to provide the battlefield commander with timely, essential intelligence information in real or near-real time. The system must include, but not necessarily be limited to, a single multipurpose airborne platform which can carry the sensor systems that will perform the roles of surveillance, reconnaissance, target acquisition and electronic warfare. The platform should be capable of multisensor employment without requiring a ground change of modules. It must be data-linked to the ground and operate in instrument meteorological conditions.

ADVANCED SCOUT HELICOPTER

General. The Advanced Scout Helicopter (ASH) will be a light, highly survivable helicopter dedicated to conducting reconnaissance, aerial observation, security and target acquisition/designation functions, day and night, in all intensities of conflict. In performing these roles, the ASH will operate in air cavalry, attack helicopter and field artillery units. It will be able to detect, identify, and locate targets at standoff ranges using nap-of-the-earth tactics. It will be able to remain on station for extended periods and have an accurate navigation system for precise target location. The design is to be optimized for maximum stability and maneuverability during hovering flight and during NOE flight.

Operational/Organization Concepts. The Advanced Scout Helicopter will operate as a part of a scout/attack helicopter team. The primary units to be equipped with the ASH are attack helicopter, air cavalry, and field artillery units. The helicopter will be used primarily for reconnaissance, security, aerial

observation, and target acquisition missions. Threat weapons in the forward battle area will require that these missions be conducted at standoff ranges and at nap-of-the-earth altitudes for increased survivability.

The ASH must be capable of communication with all Army ground units, other Army aerial vehicles, and other aerial and ground-based attack systems. Additionally, the ASH will remain on station for extended periods of time, monitoring enemy movement, controlling combat forces, and participating in poststrike analysis.

The Advanced Scout Helicopter will be required to perform throughout the range of environmental and climatic categories where U.S. forces can be expected to operate and will be exposed to the entire spectrum of threat formations and weapons normally encountered in the forward battle area (i.e., individual weapons, crew-served automatic weapons, automatic weapons on armored vehicles, AA weapons, and certain surface-to-air missiles).

System Characteristics. A preliminary listing of the ASH system characteristics are presented in table AM–U.

TABLE AM–U
ASH SYSTEM CHARACTERISTICS

ESSENTIAL CHARACTERISTICS	• The ASH system shall provide reconnaissance, security, target acquisition and precision designation functions during day and night VMC and perform limited reconnaissance and security functions during IMC. • Aircraft performance and flight handling characteristics criteria specified for the Advanced Scout Helicopter will be compatible with the requirements for the AAH and UTTAS aircraft systems. • A flight crew of two is required, pilot and copilot/observer. The aircraft will be donfigured so that one pilot can perform all duties while flying the aircraft, but dual flight controls are required. • Ballistic protection is required.
AVIONICS	• As a minimum, the Advanced Scout Helicopter will have installed the basic flight instruments required for instrument flight as specified by AR 95-1. • An airspeed indicator capable of accurately measuring and portraying airspeeds compatible with operational requirements is required. • An absolute altimeter is required. • A low-level, tactical navigation system is required. • If available within the timeframe, the aircraft should have provision for communications that will enable continuous, secure non-line-of-sight communications.
VISIONICS	• A target acquisition subsystem is required • A pilot's night vision subsystem is required to provide the pilot a capability to conduct nap-of-the-earth night operations.
TARGET LOCATION/ DESIGNATION	• A target designation subsystem with rangefinder and target location subsystem is required.
RELIABILITY AND MAINTAINABILITY	• Built-In-Test-Equipment (BITE) shall be incorporated to identify malfunction of specific modules and subsystems and to accomplish "on aircraft" maintenance.
SURVIVABILITY EQUIPMENT	• State-of-the-art countermeasure protection against visual, aural, infrared and electronic systems will be incorporated in the design of the ASH.

Vehicle Concepts. One concept of the ASH is the conventional helicopter shown in figure AM–10. The conventional helicopter provides for good, low-speed capability and good maneuverability at low forward speed. If rotors with hub moment capability are employed, then good agility to meet nap-of-the-earth flight can be achieved readily. The pure helicopter, however, becomes limited if high agility is required at higher flight speeds.

OV-X SYSTEM

The OV-X System will provide real-time intelligence/combat information to Corps and Division Commanders. The OV-X platform will provide a common air vehicle to all organic corps imagery and electromagnetic intelligence systems as presently constituted in the Aerial Exploitation Battalion, Military Intelligence Group Corps. Considerations such as weight, size, electromagnetic environment, and mission frequencies may preclude the incorporation of all airborne intelligence-gathering systems simultaneously on a single airborne platform. Furthermore, some systems may require dedicated platforms because of unique configuration requirements, such as permanent installation of special antennas. However, even where this is the case, there should be maximum achievable commonality among all systems, including the platforms and ancillary equipment.

The system will replace the OV-1, RV-1, RU-8, and RV-21 (three OV-1 and seven RU-21) currently used to perform RSTA and EW roles. A valid requirement exists for an OV-X system. A draft LOA is presently being staffed to cover the development of the OV-X system.

To meet the operational employment concept, the OV-X system design should address the capabilities and characteristics shown in table AM–V.

SURVEILLANCE VTOL AIRCRAFT

The OV-X platform will only provide standoff mission capability operating from a fixed site. For penetration missions, VTOL capability will become a prime requirement. A candidate configuration for a manned VTOL platform is the tilt-rotor concept. A system description of a Surveillance VTOL Aircraft System (SUR/VTOL) is presented in table AM–W.

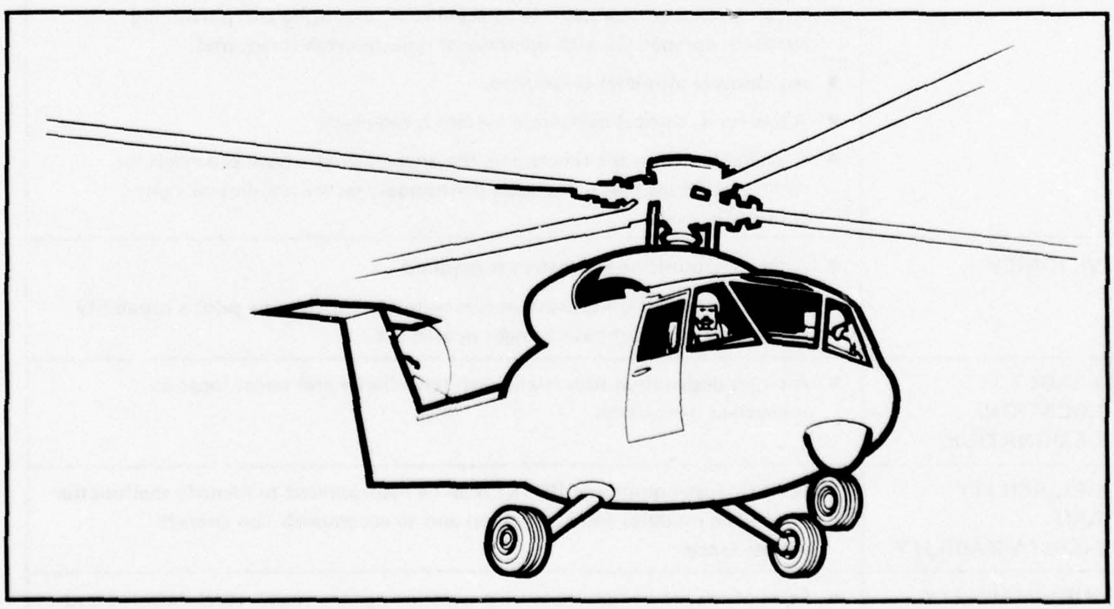


Figure AM–10. Possible helicopter concept of ASH.

TABLE AM–V
OV–X DESIGN CAPABILITIES AND CHARACTERISTICS

PLATFORM	• Operation parameters will be dependent upon mission requirements. • Capable of worldwide deployment with full mission payload. • Aircraft survivability technology should be considered in the aircraft design. • Sufficient fuselage and wing ground clearance for all external antennas. • Auxiliary power source capable of providing system power independent of propulsion system. • Environmental control system for the mission equipment and crew. • Maximum use of state-of-the-art life support equipment. • Possess sufficient RAM to be effective and supportable in the field.
DATA LINK	• The OV-X system will incorporate common, airborne multisensor data link(s) and ground control station(s). • The OV-X system will include an up and down link. • Must be capable of transmitting simultaneously to multiple ground control stations. • The airborne data link must be compatible with the other platform electronic subsystems. • The ground data link must be capable of receiving and processing multisensor data. • Both the airborne and ground subsystems must be able to operate in the EW threat environment anticipated for the post 1985 time frame. • Incorporate protection against hostile decoding during the duration of OV-X missions. • Incorporate provisions for minimization of transmission detection by the enemy. • The data link subsystem must have a minimal vulnerability to ECM.
SENSOR SUBSYSTEM(S)	• Must be capable of satisfying the corps commander's requirement for surveillance, reconnaissance, target acquisition, and electronic warfare. • Shall encompass a multisensor approach, utilizing a mix of subsystems that will enable the detection, location, recognization and identification of information/intelligence items in real time. • Will provide continuous 24-hour, near all-weather surveillance of the corps area of operations. • Information from the sensor system will be transmitted directly to multiple subscribers throughout the corps area.
AVIONICS SUBSYSTEM	• The navigation subsystem will provide data on the state of the platform (e.g., position, velocity, attitude and heading) to the sensor subsystem and/or data link. This data will be provided with sufficient accuracy and at a data rate commensurate with the OV-X system performance goals. • A terrain avoidance system capable of providing ample crew warning to allow avoidance of obstacles during night and limited visibility, if required. • Aircraft avionics should include a flight director system, autopilot, weather radar and full instrumentation for IMC.

TABLE AM–W
SURVEILLANCE VTOL AIRCRAFT SYSTEM DESCRIPTION

MISSION	• Provide immediate and continuing intelligence and target acquisition intelligence to the tactical ground commander with penetration capability.
KEY PERFORMANCE FACTORS	• Endurance. • VTOL capability.
PERFORMANCE CHARACTERISTICS	• 150-400 knot airspeed capability. • 2-3 man crew. • Agile. • Signature Minimum radar cross-section image. Minimum visual contrast profile for anticipated environment. • Self-deployable. • Mission subsystems Multispectral sensors. Stabilized electronics platform. Data link, data processing and storage. • All weather operation. • Self-contained navigation. • Unattended remote area landing system.
PHYSICAL CHARACTERISTICS	• Transportable by air or ship or self-ferry. • Accessible configuration for ground support equipment.
MAINTENANCE CHARACTERISTICS	• Built-in test equipment. • Modular replacement of components. • 0.9 probability to restore to operational status within 30 minutes after failure. • On-condition replacement of critical components. • 1 MMH/FH (scheduled) and 7.5 MMH/FH (unscheduled).
SYSTEM APPLICATION	• VTOL surveillance aircraft would replace the LOH for penetration mission requirements and supplement the OV-X with VTOL capabilities.

FIREPOWER SYSTEMS

CURRENT OPERATIONAL SYSTEMS

AH-1G

The current Army attack helicopter (armed) is the AH-1G. A discussion of the Cobra is provided in table AM–X.

DEVELOPING FIREPOWER SYSTEMS

ADVANCED ATTACK HELICOPTER – AAH

Description of System. The Advanced Attack Helicopter (AAH) is assigned the role of providing direct aerial fire in support of the combined arms team in

TABLE AM–X
CURRENT ATTACK HELICOPTER DESCRIPTION

GENERAL	• The current firepower system in Army aviation is the Bell AH-1G Cobra.
PRESENT CAPABILITIES	• The AH-1G uses UH-1 engine and drive components, together with a reduced frontal cross-sectional area and tandum seating. It has a diverse mix of armaments, including the 7.62 mm minigun, a 40 mm grenade launcher, and 2.75 inch folding fin aerial rockets. The gunner uses simple sighting and ranging. The AH-1G has an endurance of 2.5 hr and can operate at speeds up to 140 knots. It is highly maneuverable and possesses a stability and control augmentation system.
DEFICIENCIES AND SHORTCOMINGS	• The AH-1G has marginal mission payload capability and performance at higher density altitudes. It does not have an effective antiarmor weapon system or the growth potential to accept more sophisticated weapons. It lacks adequate target designation, precise navigation, and precise range and sighting equipment. It does not have night vision devices and is inadequate for IFR flight. Although its speed is adequate for the mission, its agility and maneuverability at the higher speeds are inadequate.
FOLLOW-ON SYSTEM	• The AH-1 will be replaced by the AAH for the armed helicopter system.

land combat operations. It can be based closer to the FEBA, thus providing a faster response time, and can operate at lower ceilings than a fixed-wing aircraft, thus providing a higher percentage of battlefield day and night employment. The AAH also can provide more sustained firing time during an engagement because of its hovering capability and nap-of-the-earth performance.

The firepower of the AAH will be used in conjunction with, and in support of, the firepower provided by the field artillery, tanks, armored personnel carriers, and infantry weapons of the combined arms team. The objective of the AAH is to provide quick response, highly accurate firepower to support ground operations during day, night, and marginal weather. The importance attached to the firepower function and mission of the AAH is aptly signified by its designation as one of the five highest priority projects among all Army development projects.

The AAH is a twin-engine rotary-wing aircraft functioning as a stable, manned aerial weapons system capable of delivering accurate missile, rocket, and automatic weapon fire to point and area targets. The AAH is required to perform its assigned missions of direct aerial fire under day, night, and marginal weather conditions (0.5 mile visibility, 200-ft ceiling). Low cost is a principal objective of the program. The Army intends to develop an effective AAH at the lowest possible operating acquisition cost. Each contractor's design considers operating cost, production cost, and performance. The Army has established a range of \$1.4 to \$1.6 million as the recurring flyaway cost. Major emphasis is placed on cost reduction through critical examination of operational characteristics, improved producibility, and innovative production techniques.

The AAH system is represented in figure AM–11.

Primary Mission. The primary mission of the AAH is to supply direct aerial fire as an integral part of the land combat force.

Ferry Mission. Ferry missions (auxiliary fuel tanks permitted) require a range of 800-1000 nautical miles against a 20-knot headwind. A 45-min fuel reserve at maximum range speed will be provided for flights up to 3 hr in length. For flights over 3 hr, reserve will be increased by 10 percent of the additional fuel at the airspeed and headwind required above. Two minutes at maximum continuous power will be allowed for warmup and takeoff. The mission will be performed at standard day conditions with takeoff at sea level.

Roles and Missions. The roles and missions of the AAH are presented in table AM–Y.

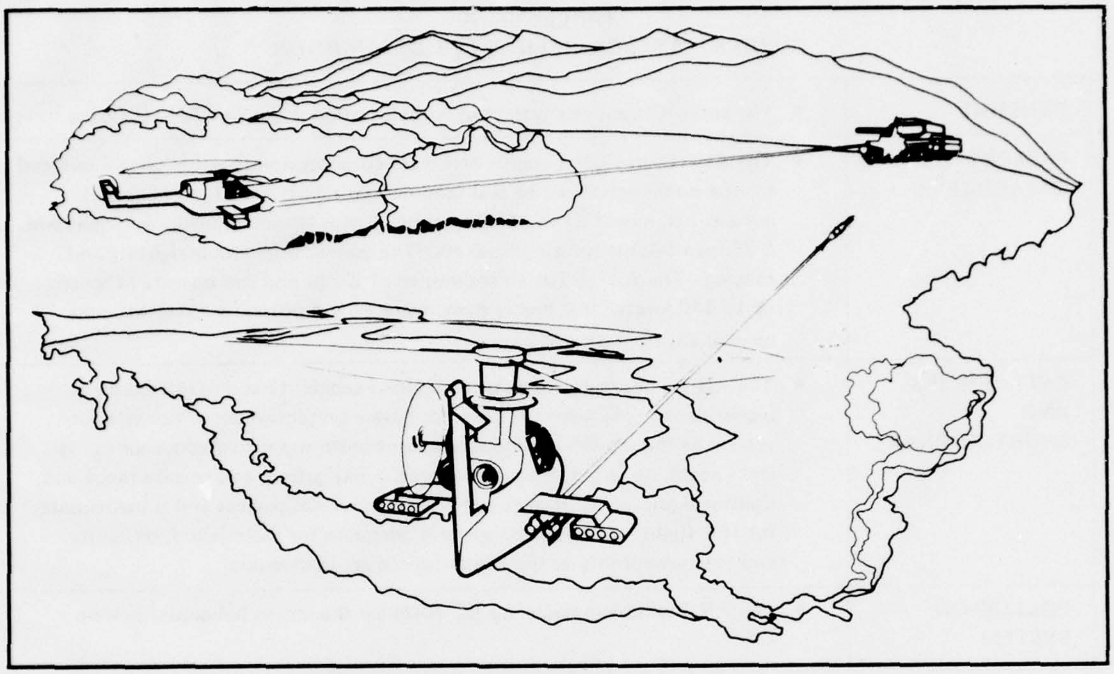


Figure AM-11. Advanced Attack Helicopter system.

TABLE AM–Y
AAH ROLES AND MISSIONS

PROVIDE	• Antiarmor/strike-force capability. • Other hardpoint target capability. • Standoff antitank capability. • Antipersonnel capability. • Area antiarmor/antimaterial capability. • LZ preparation and support during airmobile assault. • Additional fire support to airmobile movements. • Discriminating fire support for all offensive and defensive operations in built up area, (i.e., combat in cities). • Target identification and handoff. • Aerial escort during movement of forces to include airmobile operation, long range patrol, insertion/extraction escort, medical evaluation/resupply escort, and convoy protection. • Suppressive fires during assault landings and extractions. • Augmentation and extended range of other fire support means.
CONDUCT	• Armed reconnaissance. • Economy of force operations. • Screening, flank, and covering force operations. • Rear area security operations.

Performance Characteristics. The AAH major performance characteristics are delineated in table AM–Z.

Mission Reliability. The following discussion defines the mission reliability requirements listed in table AM–Z:

- The aircraft will be designed to have a mission reliability of not less than 0.95 based on 1 hr of mission time. Mission reliability is defined as the probability of completing a mission and landing at a predetermined area without an equipment malfunction or failure that precludes successful completion of the mission, given that the equipment was operationally ready at the start of the mission. The stated aircraft mission reliability requirements include all Government furnished property (GFP) but does not include the area weapon subsystem, 2.75-inch FFAR, point target weapon subsystem and the HELLFIRE Modular Missile System (HMMS). The AAH has a separate reliability for the area weapon subsystem as a probability of fireout of 0.92 to 0.94 for a 800 round complement.
- The system reliability will be 0.70 based on 1 hr of mission time. System reliability is defined as the probability that the AAH system (less expendable ordnance) while performing its specified function under intended flight conditions will incur no failures that require unscheduled maintenance.
- The MTBR of aircraft major dynamic components will be not less than 1500 flight hours for both scheduled and unscheduled removals with 300 hr between inspections.
- The MTTR as defined per MIL–STD–721B for Aviation Unit Maintenance Support maintenance will be 0.65 to 0.90 hr.
- The MMH/FH for Aviation Unit Maintenance and Intermediate Support Maintenance will be 8.0 to 13.0 hr. The MMH/FH for depot-level maintenance will be not more than 6.5 to 10.7 hr. These requirements are direct productive maintenance requirements as defined in TM38–750–1 and include subsystems.

Physical Characteristics. Principal subsystem physical characteristics are shown in table AM–AA.

Configuration. The AAH has a four blade, fully articulated rotor with a diameter of 48 ft. The tail rotor has two semi-rigid, teetering hubs with four blades positioned approximately 55° and 125° apart

TABLE AM–Z
AAH PERFORMANCE CHARACTERISTICS

KEY PERFORMANCE FACTORS	• Ability to acquire and destroy targets. • Survivability.
PERFORMANCE CHARACTERISTICS	• Hover OGE at 4000 feet 95°F, VROC 450-500 fpm at 95 percent intermediate power, zero wind 145-175 KTAS cruise speed at 4000 feet, 95°F using not more than maximum continuous power. • Endurance of not less than 1.83 hours at 4000 feet, 95°F based on: 8 minutes at maximum continuous power 30 minutes at 0-40 KTAS at DGW 12 minutes at 80-100 KTAS at DGW with mission stores 5 minutes of cruise speed at DGW 25 minutes HOGE at DGW 30 minutes reserve at maximum range speed, at DGW minus expendable ordnance and fuel consumed in above conditions • 800-1000 nautical mile ferry range against 20-knot headwind (auxiliary tanks permitted). • IR suppression. • Marginal weather day and night mission capability.

TABLE AM–AA
AAH PHYSICAL CHARACTERISTICS

WEAPONS SYSTEM	• Point Target Subsystem This primary subsystem will be used to defeat armor and other point type targets. The HELLFIRE Modular Missile System is required for the copilot/gunner with a day and night capability using the Target Acquisition and Designation System (TADS). • Area Weapon Subsystem. The Area Weapon Subsystem will consist of a flexible turret mounting a 30 mm automatic weapon. The 30 mm dual purpose HEDP round has not been combat tested but its design has been optimized for light armor point targets. • Aerial Rocket Subsystem This subsystem will provide rocket fire with the 2.75-inch FFAR. The subsystem will provide in-flight selectivity of various warheads and fusing options. The subsystem will be integrated into the external stores subsystem and fire control subsystem.
FIRE CONTROL SYSTEM	• The fire control subsystem will be a totally integrated subsystem consisting of the TADS, air data sensors, aircraft attitude and velocity sensors, pilot and copilot helmet sights, fire control computer, and all associated controls and displays necessary for the delivery of firepower. The stabilization and control accuracy of the TADS will be consistent with performance requirements necessary for autonomous designation of point targets for the laser HELLFIRE missile. The day/night range requirements for TADS are classified CONFIDENTIAL.
EXTERNAL STORES	• Four external stores stations will be provided. Each will be capable of missile and rocket stores carriage and operation, and be equipped to provide in-flight elevation and depression. Each station will be capable of carrying auxiliary fuel stores if required to meet ferry mission requirements.
CREWSTATION ARMOR	• Seat Armor Armor protected seats are required for both crewmembers. The seats must provide maximum protection for the head, neck, and torso area of the aircrewman's body (exclusive of the chest area and forward hemisphere) against 12.7 mm AP with an impact velocity of 1600 fps and zero degrees obliquity. • Airframe Armor Armor is considered only as a last resort after all methods of passive defense have been considered. For the 12.7 mm API and 23 mm HEI threats, redundancy, damage tolerance and vulnerability reduction design features contribute to a high degree of vulnerability reduction; whereas armor contributes to a smaller degree of vulnerability reduction and is used only in areas where damage tolerance cannot be achieved. Transparent armor of sufficient strength to defeat the fragmentation and survive the blast of an exploding 23 mm HEI will be placed between the crewmembers to preclude incapacitation of both crewmen from a single projectile. Nontransparent armor may be used as a barrier between crewmembers in those areas not affecting the aft crewman's external vision envelope.

TABLE AM–AA (Continued)

MAIN ROTOR GROUP	• Blade Construction. Blades will be individually interchangeable. The design will provide for erosion protection, limited operation at treetop level (with ensuing strikes by small branches within confined areas without catastrophic blade damage) and minimal probability of a catastrophic failure after a hit by a 23 mm HEI projectile. • Blade Tracking and Balance. Tracking and balancing techniques will be simple and will eliminate the need for test flights after tracking, balancing, and blade folding.
NAVIGATION SYSTEM	• Navigation will be doppler system which provides self-contained, low level navigation capability. Aircraft and target position will be continuously provided by digital readout in UTM and LAT/LONG coordinates along with selectable range, bearing, ground speed and wind information.
SURVIVABILITY	• Infrared suppression will be engineered into the system by reducing surface emissivity of the engine group and exhaust plume detactability. • Self-sealing, crashworthy fuel cells will be provided.
TRANSPORTABILITY	• The AAH shall be transportable in a C-141, C-5A, and AMST.

in azimuth. Primary control of both rotors is mechanical actuation of the hydraulic power control subsystem to position and control the swashplates. An electro-hydraulic backup control system is provided for use in case of failure or jam in the mechanical system between either crew station and the hydraulic actuators. A thru-axis stability augmentation system is incorporated.

The TADS/PNVS turret mounted sensors are located on the nose of the aircraft. The 30-mm area weapon is located under the fuselage on the structure separating the two crew stations. The pilot position is aft and above the copilot/gunner position. The two T700-GE-700 turboshaft engines are mounted on each side of the fuselage aft of the main rotor and above the wing. The engines drive the main transmission through engine mounted gearboxes, interconnecting shafts and integral freewheeling units. The tail rotor is driven by shafting connecting the main transmission, intermediate and 90° gearboxes. Figure AM–12 shows the AAH in three-view.

Key Operational Capability. The key operational capability desired in the AAH is the disruption and destruction of enemy armor formations. This task includes attack of enemy tanks, other armored vehicles, deployed troop formations both mounted and dismounted, assembly areas, command posts, and forward logistic complexes.

Current and Planned Activities. Requests for proposals (RFPs) were issued to the principal helicopter manufacturers on 15 November 1972. Proposals were received on 15 February 1973 and source selections were announced on 22 June 1973. Development go-ahead from the Deputy Secretary of Defense was announced on 19 July 1973. Bell Helicopter Textron and the Hughes Helicopter Company were awarded competitive development contracts under which they each built two flying prototypes and one ground test vehicle. A competitive flight test and evaluation was conducted by the Army from June through December 1976. On 10 December 1976, Hughes Helicopters was selected as the contractor to accomplish full scale development and integration of the AAH weapon system.

FUTURE FIREPOWER SYSTEMS

GENERAL

The employment of Army aviation units in a high threat environment will have the greatest effect on the attack helicopter in meeting the Army aviation objective of providing the commander with the mobility, firepower, and staying power needed to win the first battle. Increased emphasis must be placed on survivability, particularly through terrain flying techniques. However, other system requirements such as dash speed and endurance must not be overlooked.

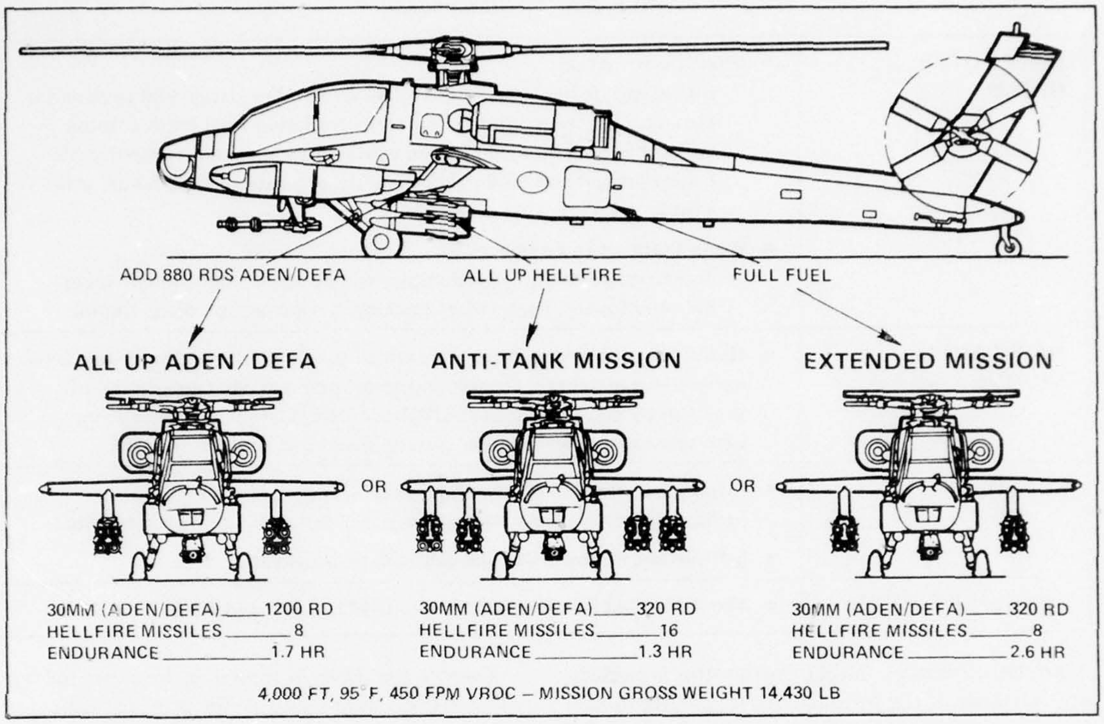


Figure AM–12. YAH-64A configuration.

AERIAL ATTACK SYSTEM

R&D efforts are necessary to continue technological improvements in the systems key performance factors. Advancements in weapons, sensors, propulsion, aerodynamics, and structures as well as tactics may well lend to the AAH being behind the state of the art in the early 1990s. One postulated R&D planning concept for the replacement of the AAH is the Advanced Aerial Weapons System (AAWS). This vehicle would most likely be a multiengine aircraft with VTOL capability for operation in and out of forward bases. To attain the desired dash speeds, conversion to an airplane type operation is indicated. Possible aircraft concepts include augmented thrust helicopter, tilt rotor, tilt wing, and deflected thrust. Possible weapons include advanced fire-and-forget missiles, antimissile missile, and air-to-air weapons. A possible tilt rotor configuration of the AAWS is shown in figure AM–13 and the system description is presented in table AM–AB.

TACTICAL MOBILITY

To provide a complete combined arms team, R&D planning efforts should include a Light Attack Helicopter (LAH) to supplement the AAH by providing economical armed reconnaissance and fire support to small combat units. An LAH system description is presented in table AM–AC.

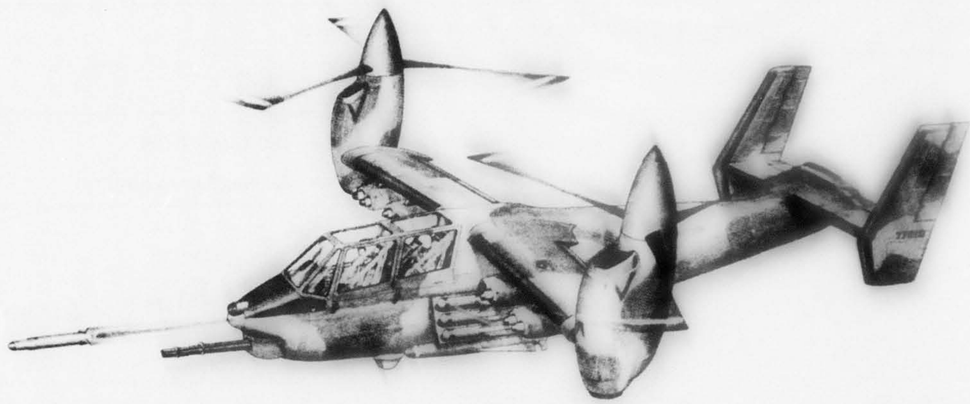


Figure AM–13. Tile rotor version of AAWS.

TABLE AM–AB
ADVANCED AERIAL WEAPONS SYSTEM DESCRIPTION

MISSION	• Provide area and point target suppression/kill capability. • Offer security and escort to troop carrying helicopters. • Provide extended area reconnaissance.
KEY PERFORMANCE FACTOR	• Ability to acquire and destroy targets. • Survivability.
PERFORMANCE CHARACTERISTICS	• 250-400 knot airspeed capability. • All-weather operational capability. • Self-deployable. • 3-hour endurance at cruise speed. • Auxiliary power augments lift/thrust. • Self-contained navigation.
PHYSICAL CHARACTERISTICS	• Transportable in C-5A. • Self sealing fuel tanks.
MAINTENANCE CHARACTERISTICS	• 300-hour periodic inspection. • On-condition replacement of critical components.
SYSTEM APPLICATION	• The AAWS would be a replacement for the Advanced Attack Helicopter currently being developed.

TABLE AM–AC
LIGHT ATTACK HELICOPTER DESCRIPTION

MISSION	• Armed reconnaissance. • Area suppression and point target destruction.
KEY PERFORMANCE FACTOR	• Ability to acquire and destroy targets. • Survivability.
PERFORMANCE CHARACTERISTICS	• 120-150 knot airspeed. • 450 fpm VROC. • 2.0 hour endurance. • All weather capability.
ARMAMENT	• 7.62 flexible machine gun. • Missile System consisting of: HELLFIRE Modular Missile System (4 rounds); or TOW Missile System (4 rounds); or Laser Beamrider Missile System (4 rounds).
SYSTEM APPLICATION:	• The LAH will supplement the AAH by providing economical armed reconnaissance and fire support to small combat units.

COMBAT SERVICE SUPPORT SYSTEMS

CURRENT OPERATIONAL SYSTEMS

UTILITY MISSION SYSTEMS

The current standard Army aircraft performing the utility mission of the combat service support function is the UH-1 helicopter. A discussion of the UH-1H is presented in table AM–F.

MEDIUM LIFT MISSION SYSTEM

The CH-47C is the current Army medium lift helicopter. A discussion of the CH-47C is provided in table AM–G.

CARGO TRANSPORT MISSION SYSTEM

The CH-54B is the current Army cargo transport helicopter. A discussion of the CH-54B is presented in table AM–H.

DEVELOPING COMBAT SERVICE SUPPORT SYSTEMS

UTILITY MISSION SYSTEM

The UTTAS, which is under development, will fulfill the utility mission of the combat service support function. However, usage and mission equipment will vary as the need dictates. Refer to table AM–A for location of discussion material on the UTTAS.

MEDIUM LIFT MISSION SYSTEM

The follow-on system for the current CH-47 fleet will be the CH-47 Modernized Medium Lift Helicopter. Refer to table AM–A for location of discussion material on the CH-47D.

CARGO TRANSPORT MISSION SYSTEM

There are no cargo transport helicopter system development efforts under consideration by AVRADCOM R&D at this time.

FUTURE COMBAT SERVICE SUPPORT SYSTEMS

UTILITY MISSION SYSTEM

Although there are no AVRADCOM R&D efforts that directly relate to a future utility mission for the combat service support function, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed. In addition, a Light Utility Helicopter with performance characteristics compatible with the ASH is also needed to assume many of the missions associated with mobility, combat service

support, and command, control and communication. A description of the LUH is provided in table AM–O.

MEDIUM LIFT MISSION SYSTEM

There are no medium lift aircraft systems under consideration by AVRADCOM R&D as a replacement for the CH-47 Modernized Medium Lift Helicopter.

CARGO TRANSPORT MISSION SYSTEM

The Heavy Lift Helicopter concept is needed to satisfy future cargo transport missions associated with the combat service support functions. Refer to table AM–A for location of discussion material on the HLH.

COMMAND, CONTROL AND COMMUNICATION SYSTEMS

CURRENT OPERATIONAL SYSTEMS

AVIATION SUPPORT

The current Army aircraft providing command, control, and communications support to the field commander are the LOH and UH-1. A discussion of the LOH is presented in table AM–Q and of the UH-1H in table AM–F.

DEVELOPING COMMAND, CONTROL AND COMMUNICATION SYSTEMS

AVIATION SUPPORT

The UTTAS, which is under development, will perform the aviation support mission of the command, control and communications functions for the battalion commander and higher echelon levels. Refer to table AM–A for location of discussion material on the UTTAS.

FUTURE COMMAND, CONTROL AND COMMUNICATION SYSTEMS

AVIATION SUPPORT

Although there are no AVRADCOM R&D efforts that directly relate to a replacement aircraft for the UTTAS, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed. A possible tilt rotor configuration is depicted in figure AM–14.

A Light Utility Helicopter with performance characteristics compatible with the ASH is needed to assume many of the mission associated with aviation support as well as mobility and combat service support. A description of the LUH is provided in table AM–O.

Improving the individual mobility of the infantry soldier has long been an Army objective. Because of high life-cycle costs, high levels of maintenance and required support, and the degree of operator training required, this objective has not been attainable for the individual soldier.

The system description of one such possible system, the Individual Tactical Aerial Vehicle, is shown in table AM–AD.

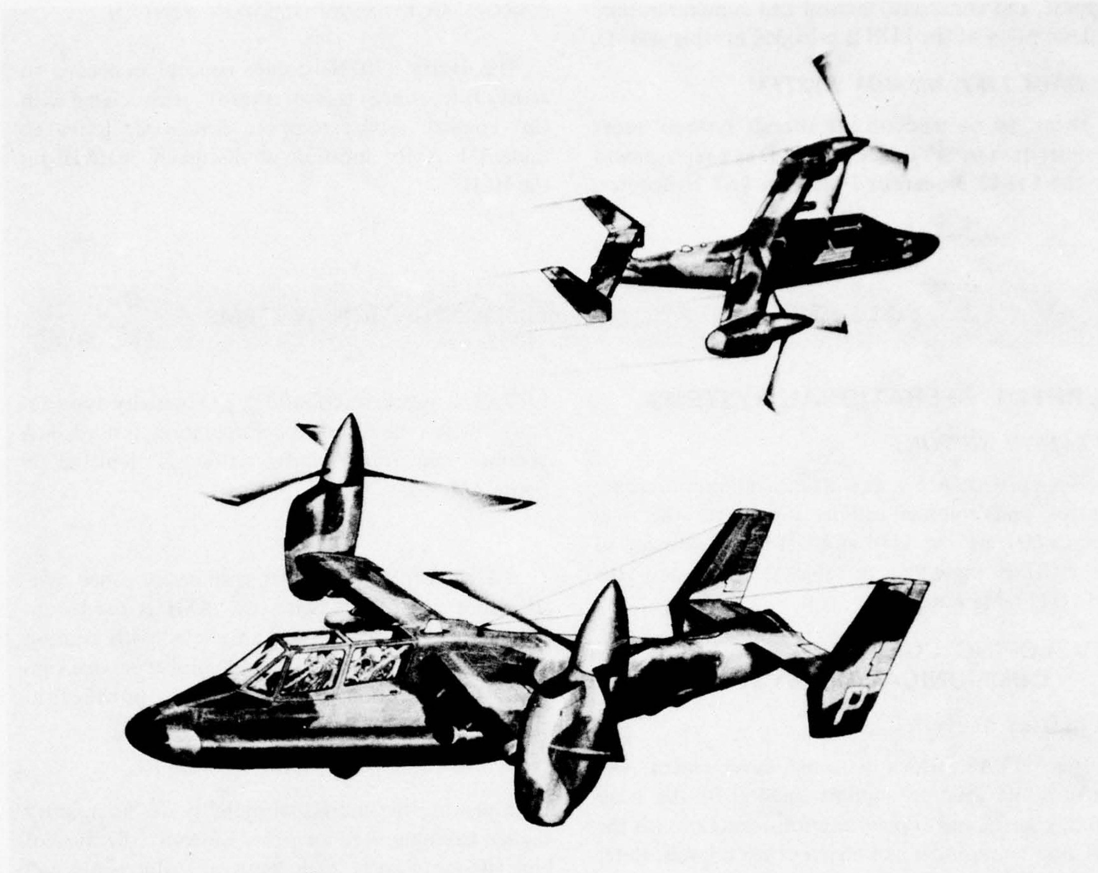


Figure AM–14. Tilt rotor version of an aviation support role aircraft.

TABLE AM–AD
INDIVIDUAL TACTICAL AERIAL VEHICLE SYSTEM DESCRIPTION

MISSION	• Extend intelligence-gathering capability of the ground commander. • Deployment of small man-portable defense weapon systems.
KEY PERFORMANCE FACTOR	• NOE maneuverability. • Unique survivability capabilities. • Low cost. • Easy to operate.
PERFORMANCE CHARACTERISTICS	• Hover 4000 ft, 95°F, OGE • 40-60 knot airspeed. • 1/2-hour endurance. • Operation in adverse weather conditions. • 30 mile range. • 300 lb payload.
PHYSICAL CHARACTERISTICS	• Highly survivable. • Minimum maintenance. • Minimum training.
SYSTEM APPLICATION	• Provide mobility to the individual soldier.

INTRODUCTION

ANALYSIS OF AIRCRAFT CONCEPTS

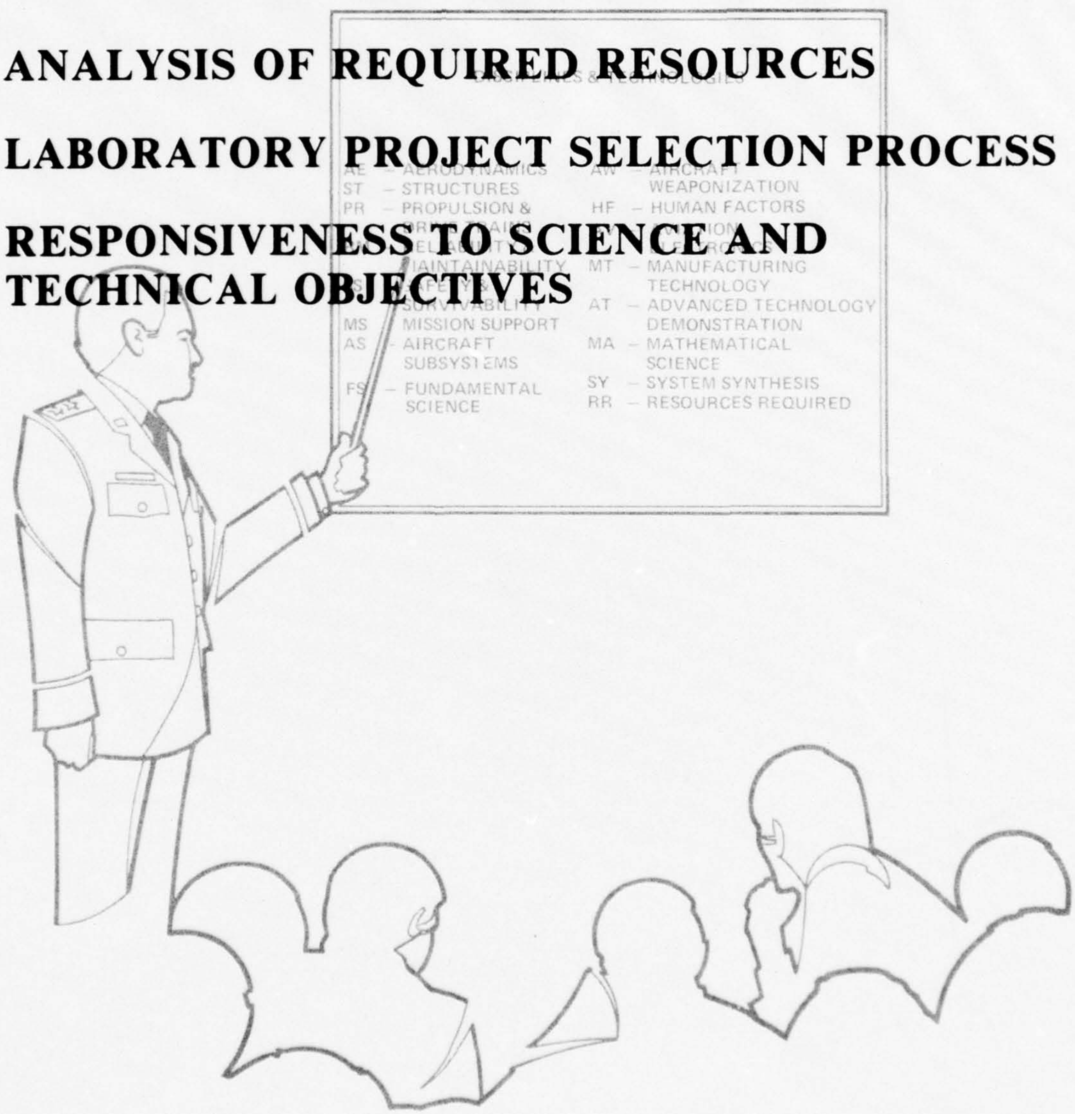
TECHNOLOGICAL REQUIREMENTS

ANALYSIS OF R&D TASKS

ANALYSIS OF REQUIRED RESOURCES

LABORATORY PROJECT SELECTION PROCESS

RESPONSIVENESS TO SCIENCE AND TECHNICAL OBJECTIVES



INTRODUCTION

The Airmobile Systems section of the Army aviation RDT&E Plan defines specific performance requirements for many of the near-term aircraft systems. For systems projected further into the future, more general performance requirements are described. In either case, it is possible to identify the most promising aircraft concepts to best satisfy these requirements and the research efforts needed to develop the technology base to support these concepts. In some instances, a specific airmobile system description includes technological deficiencies (voids) that must be resolved by research to permit the development of a feasible system. This "demand pull" effort is discussed in the General Introduction section of the Plan.

Agility, endurance, payload, maneuvering precision, survivability, reliability, and efficiency are some of the important mission requirements that determine the ways that V/STOL technology can meet the airmobile needs of the Army. With few exceptions, projected mission requirements and proposed airmobile systems for the next two decades call for hovering capability, or at least the ability to take off and land vertically in support of forward-base operations. A variety of airplane, rotorcraft, and compound configurations conceptually have the potential to meet this requirement, but the rotary-wing configuration is presently the most attractive from an aerodynamic standpoint because of its hovering efficiency, its relatively mild downwash and noise characteristics, and its ability to autorotate. These are important factors affecting performance, detectability, and survivability.

ANALYSIS OF AIRCRAFT CONCEPTS

Chart TI–I shows a morphology of possible VTOL concepts. However, the Army's requirements for hover efficiency and ability to live with the troops limits consideration for most of the systems to rotary-wing concepts because, as is indicated in figure TI–1, the hover efficiency is reduced and the downwash velocity increased with increasing disc loading. Although the helicopter appears to be the main contender, there are trade-offs to be addressed because cruise performance improves with increasing disc loading.

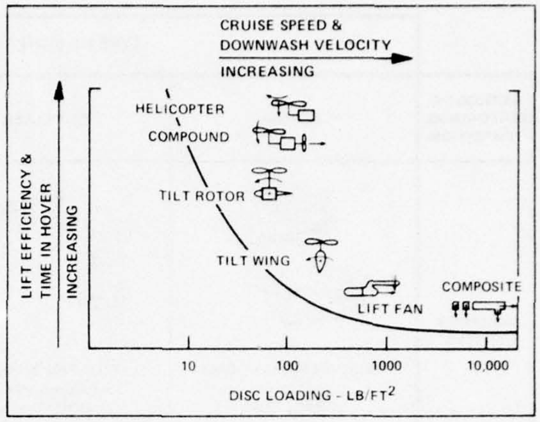


Figure TI–1. Generation of VTOL aircraft performance characteristics with disc loading.

The term "rotary-wing configuration" is used herein to denote a primary thrusting element consisting of two or more rotating blades, that is, a conventional helicopter rotor, and having a low effective disc loading of 15 psf or less. As shown in figure TI–1, this disc loading is much less than other VTOL configurations, such as the tilt wing VTOL that usually has a disc loading of over 100 psf, or the ducted fan VTOL that has a disc loading of about 500 psf.

Low-disc loading configurations offer other important operational advantages besides efficiency. Low disc loading is directly related to low downwash velocity and therefore low slipstream energy content. An important consequence of this flow environment is that surface debris is less likely to be recirculated or ingested during maneuvers near the ground. A related effect is the reduced heating of the neighboring atmosphere during extended hovering, thus avoiding a performance loss caused by high ambient temperatures on gas turbines. Still another benefit is less noise generation and a resultant lower detectability profile during surveillance and reconnaissance activities. It should also be recognized that decreased downwash and noise are both of immeasurable importance where ground personnel operations are involved.

The user's concern, when faced with evaluating alternative aircraft, is how effectively each will perform the missions he requires. How this is accomplished through design detail is of little concern to him; however, it is important for the potential rotary-wing VTOL customer to know what influence particular mission requirements will have on the attainable mission effectiveness. Hover duration, for example, is

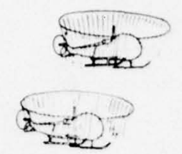
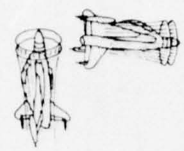
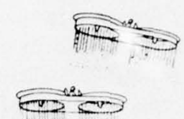
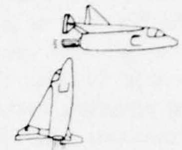
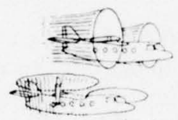
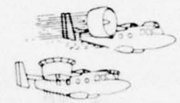
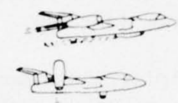
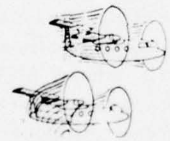
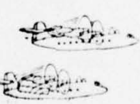
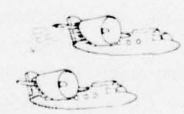
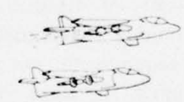
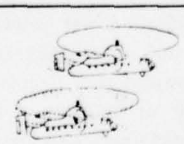
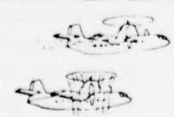
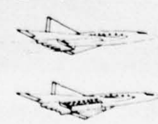
METHOD OF PERFORMING TRANSITION	TYPE OF POWERED-LIFT GENERATOR: ROTOR	PROPELLER	DUCTED FAN	TURBOJET
AIRCRAFT TILTING	 **HELICOPTERS (TYPICAL)** BELL UH-1 VERTOL CH47	 **PROP TAIL SITTERS** CONVAIR XFY-1 LOCKHEED XFV-1	 **DUCTED-FAN "JEEPS"** CHRYSLER VZ-6 PIASECKI VZ-8	 **JET TAIL SITTERS** RYAN X-13
THRUST TILTING	 **TILT ROTOR** BELL XV-3 BELL XV-15	 **TILT WING OR TILT PROP** U.S. { VERTOL VZ-2, HILLER X-18, VOUGHT XC-142, CURTISS-WRIGHT X-19 } TILT WING; CURTISS-WRIGHT X-100 TILT PROP CANADA CANADAIR CL-84	 **TILT DUCTED FAN** U.S. { DOAK VZ-4, BELL X-22A FRANCE NORD N-500	 **TILT JET** U.S. BELL ATV GERMANY EWR VJ101C
THRUST DEFLECTION	 **DEFLECTED THRUST ROTOR** KAMAN K-16	 **DEFLECTED THRUST PROP** U.S. { RYAN VZ-3, FAIRCHILD VZ-5 FRANCE BREGUET 941S	 **DEFLECTED FAN** AVROCAR VZ-9	 U.S. { BELL X-14, LOCKHEED XV-4 U.K. HAWKER SIDDELEY HARRIER GERMANY DORNIER D031, VFW/FIAT VAK-191B
DUAL PROPULSION	 **ROTOR COMPOUND** U.S. { McDONNELL XV-1, LOCKHEED AH-56A U.K. FAIREY ROTODYNE U.S.S.R. HOOP	 **PROP COMPOUND** NONE	 **FAN COMPOUND** RYAN XV-5A	 **JET COMPOUND** U.K. SHORT BROS. SC-1 FRANCE MIRAGE III-V

Chart TI–1. VTOL Configuration

one requirement that must be weighed against cruise performance (figure TI–2). Other requirements include built-in facilities and fixed useful load (which reduce disposable load), altitude and temperature requirements (which decrease gross weight and increase empty-to-gross weight ratio), size (which has square-cubed law implications), and airframe configuration (crane, internal cargo, etc.).

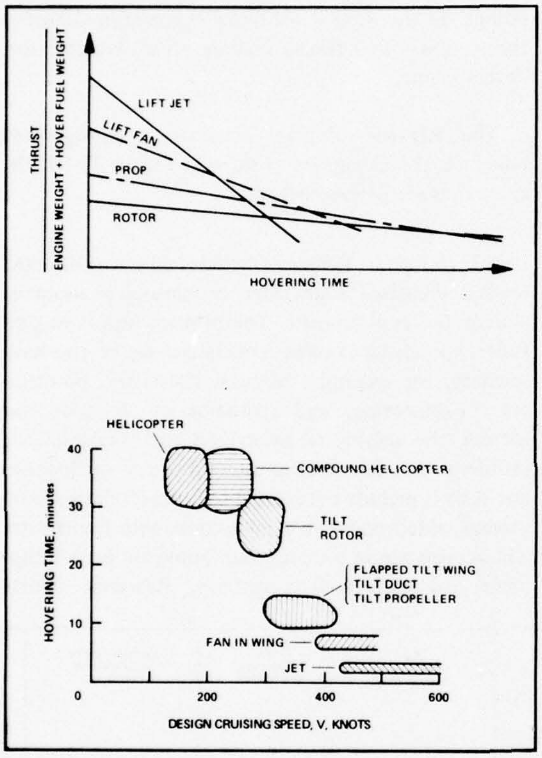


Figure TI–2. Hovering and cruise performance.

Performance requirements result from the specific mission. The ability to perform the mission is determined by basic system efficiencies, configuration design variables, weight allowance for special equipment and facilities, range, endurance, hover time, derating for altitude and temperature, and other such factors. Configuration design variables, such as disc loading, rotor solidity, rotor tip speed, and compounding, are manipulated by the designer to optimize the design. Basic system efficiencies such as rotor figure of merit, airframe drag, cruise lift/propulsion efficiency, engine specific fuel consumption, and empty-to-design gross weight ratio are functions of the state of the art.

For this Plan, all possible aircraft concepts, including VTOL, V/STOL, and STOL, were considered. Those adjudged most probable to meet projected performance requirements for each requirement are shown in figure TI–3. Projected IOC dates for each aircraft system as determined from available documentation and as constrained by political and fiscal limitations were established. Since long-term projections are less certain in detail and more basic in technological research implications, more options are retained, whereas, for a near-term system, only a single system concept remains feasible.

CANDIDATE CONCEPTS	AAH	UTTAS	ASH	RPV	CH-47D	HLH	OV-X	SUR/VTOL	AAWS	LAH	LUH	ITAV
VTOL												
AUTOGYRO				X								
HELICOPTER	X	X	X	X	X	X				X	X	X
TILT ROTOR								X	X			
ROTOR COMPOUND				X					X			X
TILT WING								X	X			
TILT DUCTED FAN									X			X
DEFLECTED FAN									X			X
FAN COMPOUND									X			X
DEFLECTED JET									X			X
STOL												
HIGH-LIFT DEVICES				X				X				
POWER AUGMENTED LIFT				X								
CTOL												
CONVENTIONAL				X			X					
OTHER												
LIGHTER THAN AIR						X						

Figure TI–3. Concepts for Army air mobility missions.

TECHNOLOGICAL REQUIREMENTS

The missions, concepts, and assigned IOC dates represent the current projection of the Army's aviation needs that have been analyzed to identify technology gaps. Following estimation of the performance requirements and operational needs, it was then possible to predict the technological developments that must be pursued in support of the specific systems and concepts that were identified. The mechanism for identifying, justifying, and establishing research projects and tasks to provide development data for integration into the system design of future aircraft is the continual conduct of conceptual and design studies of the options for the various mission requirements. Required advances in the disciplines and supporting technologies are identified by such studies. (The studies also form the basis of a

development plan.) However, the chief characteristics of air vehicle technology are its interdisciplinary nature and very broad spectrum. It is important to recognize the interfaces of the many components, equipments, disciplines, and sciences that make up the totality of the airmobile systems design problem. The many faceted interrelationships of the essential elements in the aircraft design process aligned with the life cycle phases and program categories are portrayed in chart TI–II.

If the synthesis of the aircraft system performance capabilities is a complex problem, the analysis of specified performance requirements to determine the effect on the subsystems, disciplines, and technologies is even more so. Development of the final coordinated Plan relied heavily on experience with the synthesis problem and on the projected technological trends.

Development schedules were predicted that covered, for each aircraft option, time from start of the project to projected IOC date. These schedules were used to estimate development lead time required, thus establishing the time required to achieve technological objectives necessary to meet the IOC date. The life cycle of a new aircraft system and the time and method by which technological advancements are incorporated into it vary greatly, depending on the complexity of the system, availability of new advancements, and their cost effectiveness. In general, a new aircraft experiences a life cycle that includes most of the elements shown in chart TI–II. It was assumed that contract definition (beginning engineering development) occurred, on the average, about 8 years prior to IOC, and initiation of exploratory development was required about 7 years before contract definition. The objective in all cases was to have completely developed and to have demonstrated technology on the shelf – ready for engineering design of the system – in a timely manner prior to engineering development.

The RDT&E program structure was organized based on the categories as shown in chart TI–II; the categories are defined below.

6.1 Research. Research includes all effort directed toward increased knowledge of natural phenomena and of the environment. The primary aim is to gain fuller knowledge and/or understanding of the hard sciences, for example, physics, chemistry, biomedicine, engineering, and mathematics. It does not include the solving of behavioral and social science problems that have a clear direct military application, nor does it include the solving of human relations and factors which occur in conjunction with human use and acceptance in a man/group application to equipment, materiel, and/or systems. Research efforts

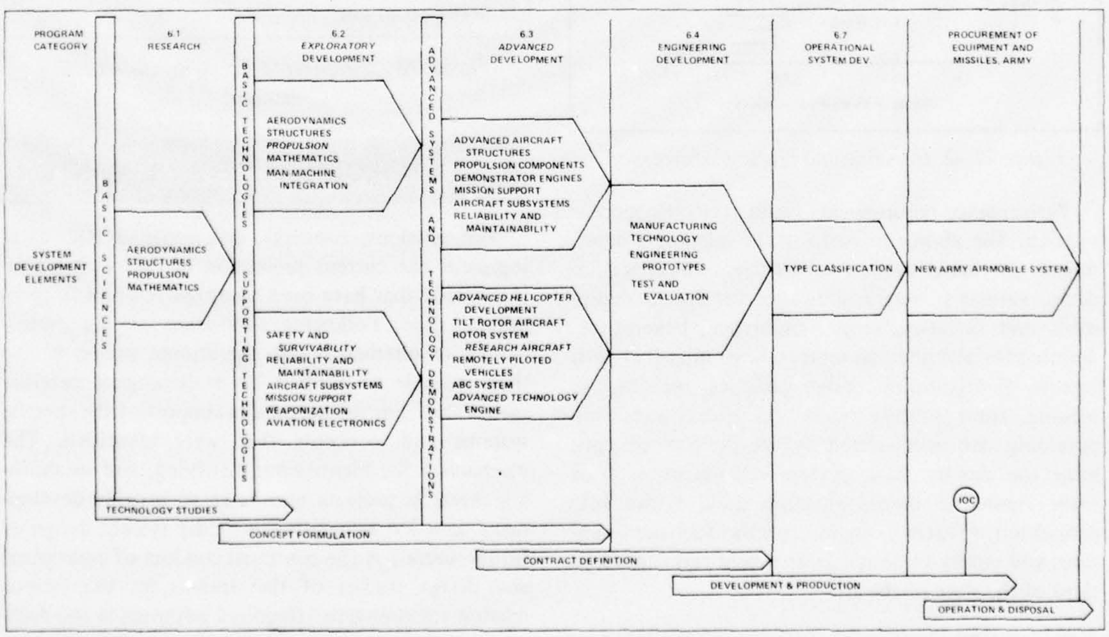


Chart TI–II. Relationships of Technologies for New Airmobile Systems

result in an increased knowledge of natural phenomena and/or improved technology.

6.2 Exploratory Development. Exploratory development includes all effort directed toward solving specific military problems short of major developments projects. It may vary from fairly fundamental applied research to quite sophisticated prototype hardware, study, programming, and planning efforts. It would thus include studies and minor development efforts. The dominant characteristic is that the effort is pointed toward specific military problem areas with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters.

6.3 Advanced Development. Advanced development includes all projects that have progressed to developing hardware for experimental or operational test. It is characterized by line item projects, and program control is exercised on a project basis. Another descriptive characteristic is the design of the items being directed toward hardware for test or experimentation as opposed to items designed and engineered for eventual military service use.

6.4 Engineering Development. Engineering development includes those development projects being engineered for military service use but which have not yet been approved for procurement or operation. It is characterized by major line item projects; program control is exercised by reviewing individual projects.

6.7 Operational System Development. Operational system development includes research and development effort directed toward developing, engineering, and testing systems; support programs; and vehicles and weapons that have been approved for production and military service employment. This area is included for convenience in considering all RDTE projects. All items are major line item projects that appear as RDTE cost of weapon project systems elements in other programs. Program control will thus be exercised by reviewing the individual research and development effort in each weapon system element.

The impact matrix presented in chart TI–III represents the relationship between key operational requirements for each of the systems considered and the technological objectives for 12 disciplines and technologies. (Mathematical Science is not listed because it does not have a first-order effect on the areas listed.) The interfaces and interdependencies among the objectives are discussed in the technology sections that follow this introduction.

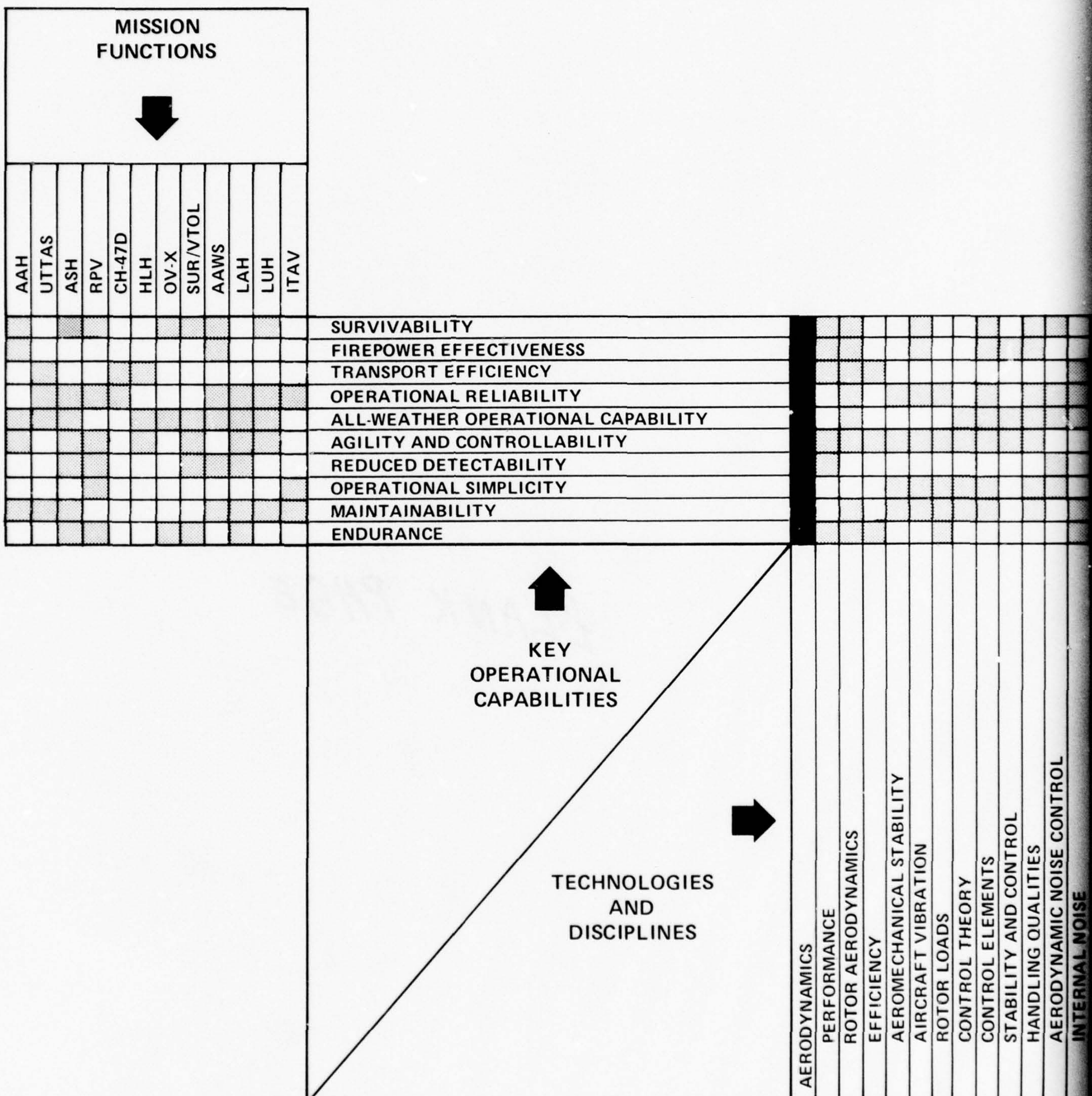
The objectives of the activities in each of the disciplines and technologies have been quantified, wherever possible, in accordance with the performance and timing requirements of the projected airmobile systems. In some areas, particularly in the basic sciences, this has not been entirely possible because the performance requirements of a particular system cannot be related directly or quantitatively to an incremental advance in a particular discipline or because a definitive parameter has not yet been defined in that discipline and, in fact, research is directed toward the definition of such a parameter.

The major portion of the planned research effort is directed toward rotary-wing aircraft, which are expected to be the prime source of Army air power in the future. However, other subsonic aircraft, capable of vertical or short takeoff and landing, have not been precluded.

ANALYSIS OF R&D TASKS

The 13 disciplines categorized as airmobile technology with supporting disciplines of Advanced Technology Demonstration, Aircraft System Synthesis, Fundamental Science, and Resources Required are presented in the following subsections of the Plan. All work objectives are categorized within the key subdisciplines and each is time-phased, quantified wherever possible, and presented graphically. Priority of effort is addressed and interactions of work objectives in each subdisciplines are portrayed graphically. Interdependencies with developments in other disciplines and technologies are discussed. Efforts in one subdiscipline cannot be redirected without careful consideration of the possible effects on other areas.

Advances in the basic aeronautical sciences and supporting technologies make up the foundations on which are laid the interdisciplinary developments and finally, the design of new systems. The combination of all these accomplishments in a pyramid-like structure is required to support demonstration of technology to attain the desired performance for each system/component. The example of figure TI–4 is for a tilt-rotor concept as applied to the intelligence mission function; it was derived from information presented in the Plan. This presentation helps to display the pacing technology areas and provides


MISSION FUNCTIONS
AAH
UTTAS
ASH
RPV
CH-47D
HLH
OV-X
SUR/VTOL
AAWS
LAH
LUH
ITAV
SURVIVABILITY
FIREPOWER EFFECTIVENESS
TRANSPORT EFFICIENCY
OPERATIONAL RELIABILITY
ALL-WEATHER OPERATIONAL CAPABILITY
AGILITY AND CONTROLLABILITY
REDUCED DETECTABILITY
OPERATIONAL SIMPLICITY
MAINTAINABILITY
ENDURANCE
KEY OPERATIONAL CAPABILITIES
TECHNOLOGIES AND DISCIPLINES
AERODYNAMICS
PERFORMANCE
ROTOR AERODYNAMICS
EFFICIENCY
AEROMECHANICAL STABILITY
AIRCRAFT VIBRATION
ROTOR LOADS
CONTROL THEORY
CONTROL ELEMENTS
STABILITY AND CONTROL
HANDLING QUALITIES
AERODYNAMIC NOISE CONTROL
INTERNAL NOISE

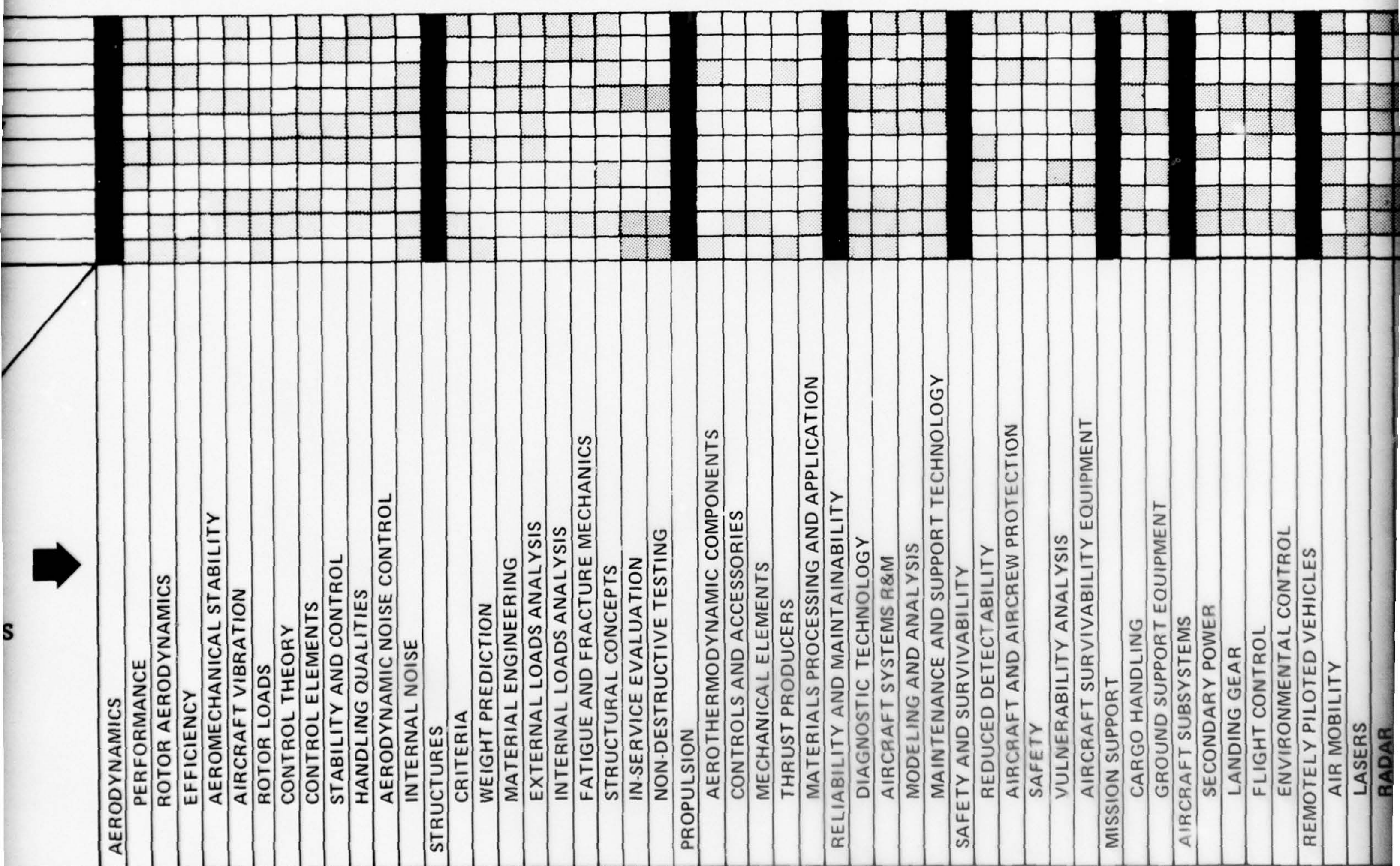
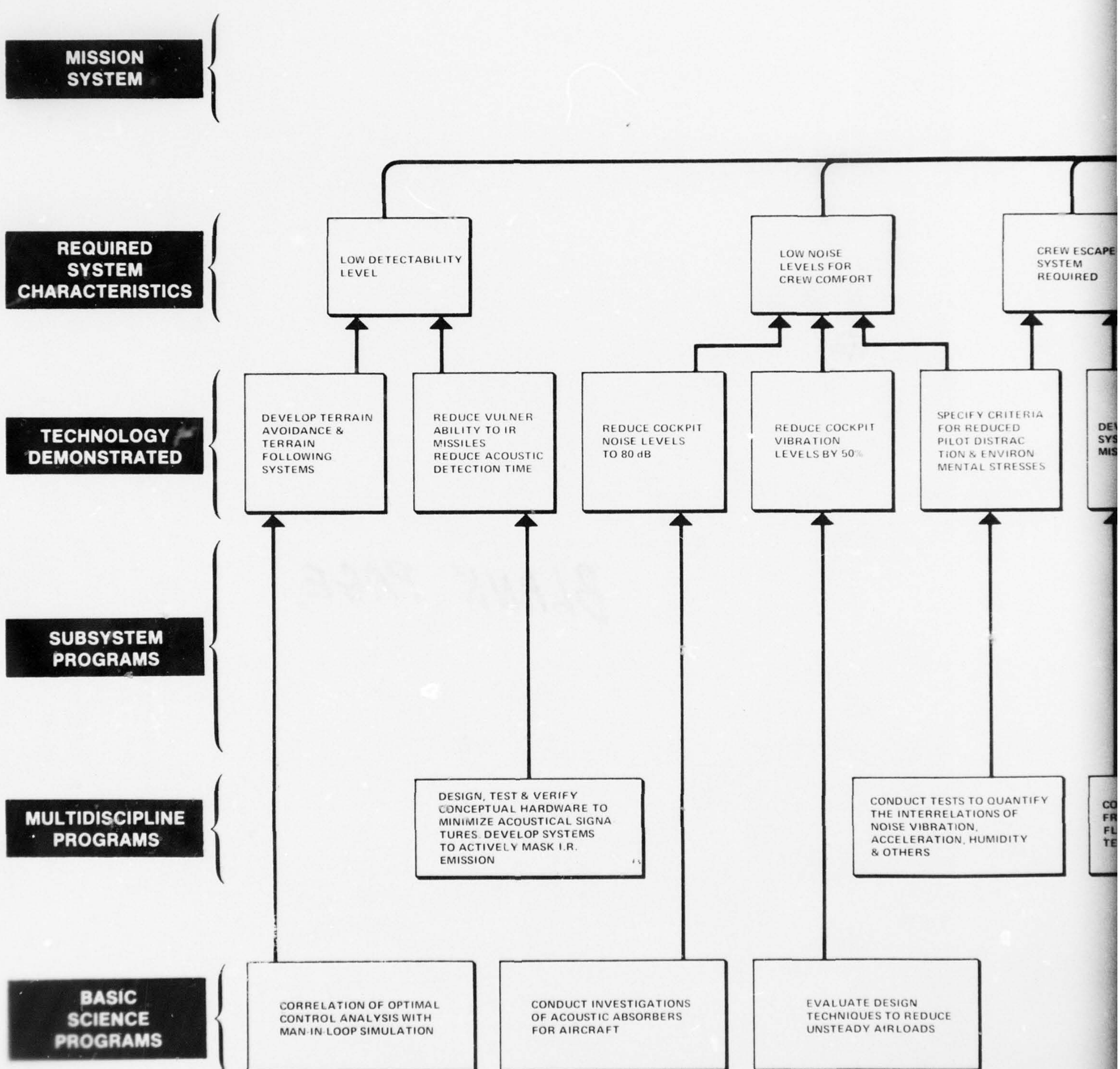


Chart TI–III. Technology Impact Matrix

2

- NON-DESTRUCTIVE TESTING
- PROPULSION
  - AEROTHERMODYNAMIC COMPONENTS
  - CONTROLS AND ACCESSORIES
  - MECHANICAL ELEMENTS
  - THRUST PRODUCERS
  - MATERIALS PROCESSING AND APPLICATION
- RELIABILITY AND MAINTAINABILITY
  - DIAGNOSTIC TECHNOLOGY
  - AIRCRAFT SYSTEMS R&M
  - MODELING AND ANALYSIS
  - MAINTENANCE AND SUPPORT TECHNOLOGY
- SAFETY AND SURVIVABILITY
  - REDUCED DETECTABILITY
  - AIRCRAFT AND AIRCREW PROTECTION
  - SAFETY
  - VULNERABILITY ANALYSIS
  - AIRCRAFT SURVIVABILITY EQUIPMENT
- MISSION SUPPORT
  - CARGO HANDLING
  - GROUND SUPPORT EQUIPMENT
- AIRCRAFT SUBSYSTEMS
  - SECONDARY POWER
  - LANDING GEAR
  - FLIGHT CONTROL
  - ENVIRONMENTAL CONTROL
- REMOTELY PILOTED VEHICLES
  - AIR MOBILITY
  - LASERS
  - RADAR
  - COMMAND AND CONTROL
  - VISIONICS
- MAN-MACHINE INTEGRATION
  - AIRCREW WORKLOAD QUANTIFICATION
  - CREW STATION ENVIRONMENT
  - INFORMATION TRANSFER
  - MAN-MACHINE DYNAMICS
  - FLIGHT SIMULATION
  - TRAINING AND MAINTENANCE
- AVIATION ELECTRONICS
  - AVIONICS SYSTEMS
  - COMMUNICATIONS
  - NAVIGATION
  - TACTICAL LANDING
  - AIR TRAFFIC MANAGEMENT
  - ENVIRONMENTAL SENSING
  - INSTRUMENTATION
  - SURVEILLANCE AND TARGET ACQUISITION
  - NIGHT VISION SYSTEMS
- OTHER
  - MANUFACTURING TECHNOLOGY
  - AIRCRAFT WEAPONIZATION

Impact Matrix



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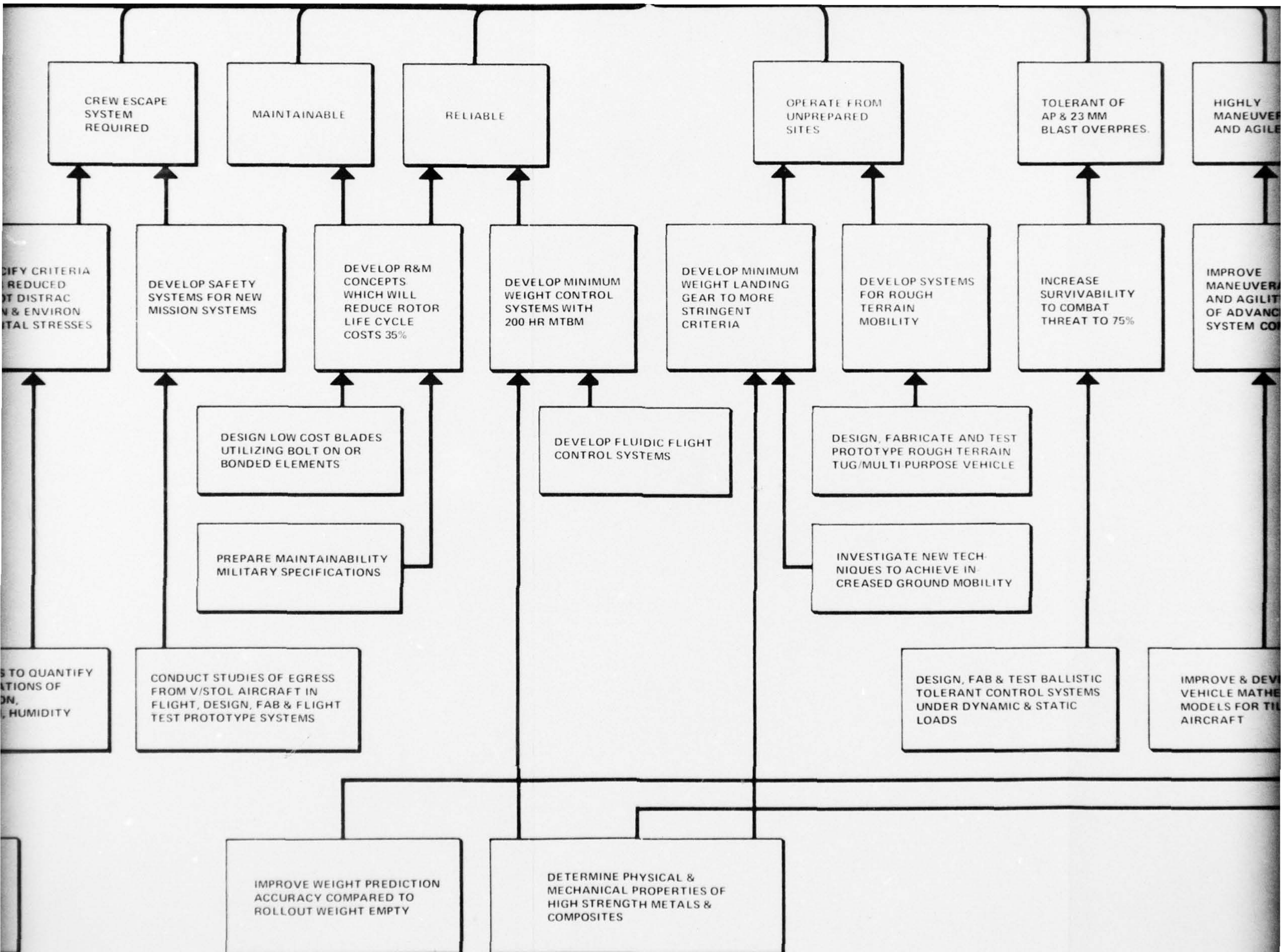
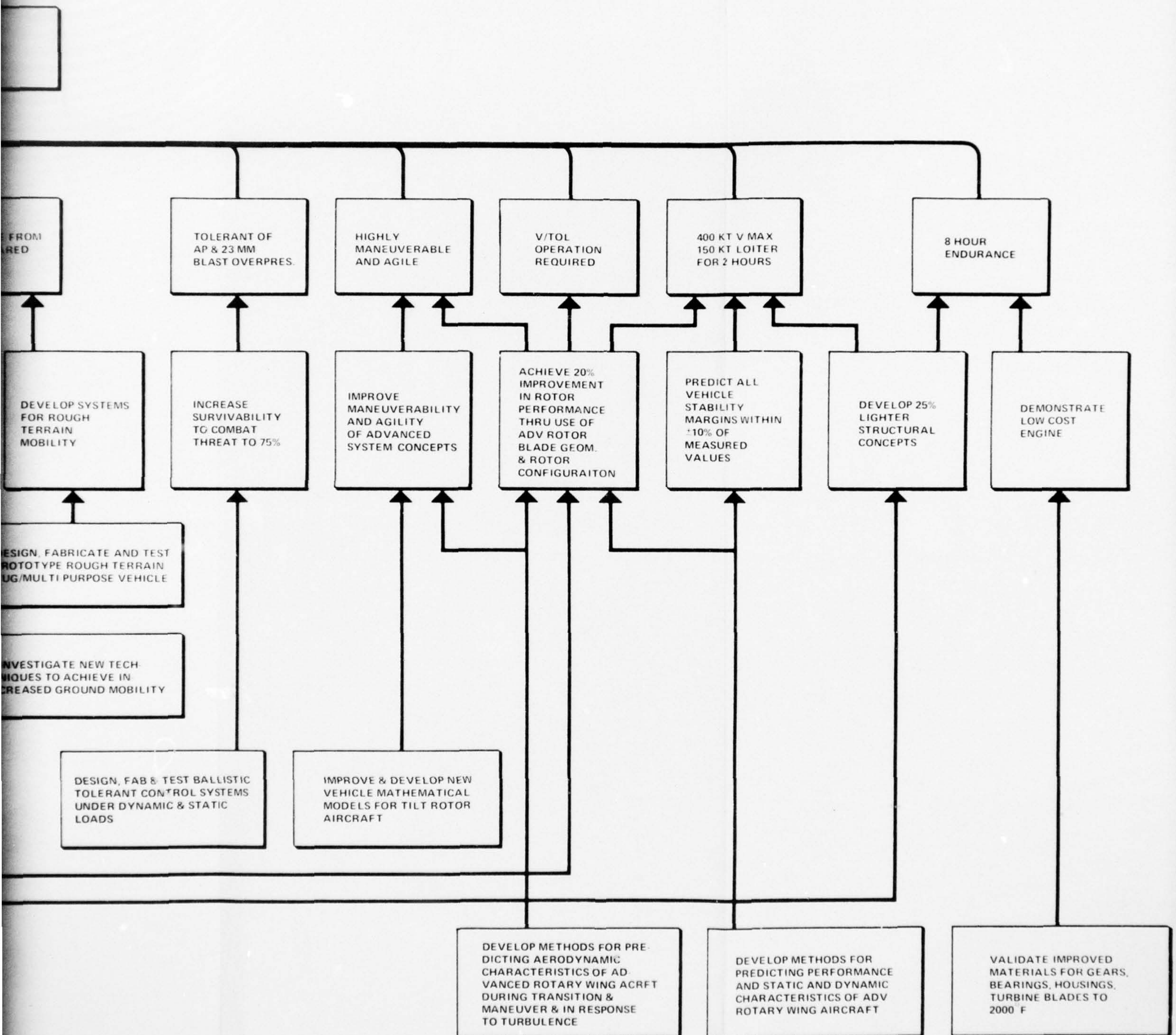


Figure TI–4. Pyramidal structure of accomplishments for SUR/VTOL and tilt rotor.

2


FROM
RED
TOLERANT OF
AP & 23 MM
BLAST OVERPRES.
HIGHLY
MANEUVERABLE
AND AGILE
V/TOL
OPERATION
REQUIRED
400 KT V MAX
150 KT LOITER
FOR 2 HOURS
8 HOUR
ENDURANCE
DEVELOP SYSTEMS
FOR ROUGH
TERRAIN
MOBILITY
INCREASE
SURVIVABILITY
TO COMBAT
THREAT TO 75%
IMPROVE
MANEUVERABILITY
AND AGILITY
OF ADVANCED
SYSTEM CONCEPTS
ACHIEVE 20%
IMPROVEMENT
IN ROTOR
PERFORMANCE
THRU USE OF
ADV ROTOR
BLADE GEOM.
& ROTOR
CONFIGURAITON
PREDICT ALL
VEHICLE
STABILITY
MARGINS WITHIN
±10% OF
MEASURED
VALUES
DEVELOP 25%
LIGHTER
STRUCTURAL
CONCEPTS
DEMONSTRATE
LOW COST
ENGINE
ESIGN, FABRICATE AND TEST
ROTOTYPE ROUGH TERRAIN
UG/MULTI PURPOSE VEHICLE
NVESTIGATE NEW TECH-
NIQUES TO ACHIEVE IN-
CREASED GROUND MOBILITY
DESIGN, FAB & TEST BALLISTIC
TOLERANT CONTROL SYSTEMS
UNDER DYNAMIC & STATIC
LOADS
IMPROVE & DEVELOP NEW
VEHICLE MATHEMATICAL
MODELS FOR TILT ROTOR
AIRCRAFT
DEVELOP METHODS FOR PRE-
DICTING AERODYNAMIC
CHARACTERISTICS OF AD-
VANCED ROTARY WING ACRFT
DURING TRANSITION &
MANEUVER & IN RESPONSE
TO TURBULENCE
DEVELOP METHODS FOR
PREDICTING PERFORMANCE
AND STATIC AND DYNAMIC
CHARACTERISTICS OF ADV
ROTARY WING AIRCRAFT
VALIDATE IMPROVED
MATERIALS FOR GEARS,
BEARINGS, HOUSINGS,
TURBINE BLADES TO
2000°F

rotor.

another aspect of the interdependencies of accomplishments in the sequential, mission-oriented sense. Similar graphical presentations can be drawn from the Plan for every system and concept projected herein and for any other to which the technology pertains.

It is apparent from an analysis of the R&D Plan that VTOL aircraft technology is expected to be significantly advanced over the 20-year time frame that is addressed. Improved rotor performance, reduced structural weight ratios, and reduced specific fuel consumption are certain to be realized. Solid-state, integrated microelectronic circuitry will enable the provision of on-board miniature computers and other devices that will greatly enhance navigation, control, and fire-control capabilities over current systems, making possible all-weather and night operations, even during terrain flying. Better reliability and fewer maintenance requirements are sure to evolve, as will self-contained test capability. The dominant objective is the development of aircraft that can survive in the hostile environment typical of Army aviation.

The advances in aircraft technology can only become an integral part of the R&D cycle when the advancement has been validated by component or system demonstration in actual or simulated flight conditions. The near-term technological advances undergoing validation are discussed in considerable detail in the Plan.

ANALYSIS OF REQUIRED RESOURCES

The precise quantitative magnitude of technological improvement that can be achieved is governed by considerations other than the purely technical. Political policy, although a major element, is impossible to predict and has not been considered. Of major importance are budgetary and schedule constraints that limit the extent of design optimization and technological advance. With limited resources, imposed economics, and prescribed goals, a logical resource allocation methodology is the key to orderly progress.

The issue of resource requirements is discussed in section RR – Resources Required. However, it is reiterated that this document presents the Plan for research and development in Army aviation and is not a program. The Plan becomes the program when the required resources in terms of funds, facilities, and personnel are provided to enable its implementation.

It is not likely that all the efforts described in this plan would be pursued or that all the goals would be achieved. Furthermore, the available options and alternatives to perform the given task diminish with time and, consequently, estimates of resource requirements are valid only on a relatively short-term basis.

LABORATORY PROJECT SELECTION PROCESS

INTRODUCTION

As stated previously, the superiority of future Army airmobile systems depends on the availability and exploration of new scientific knowledge and the development of a firm technology base to meet projected requirements. Unfortunately, there are never enough resources to undertake all of the research projects that optimum planning would indicate necessary for the development of that technology base. In many cases there are more feasible technical alternatives available to solve a particular problem than can be economically supported. The problem that faces the R&D manager is to decide which efforts are to be supported and which goals can be achieved under the conditions of limited resources. The procedure described herein and implemented in most of the following technology sections (see Technological Program Direction subsection) is the Research and Technology Laboratories method for solving the project selection problem.

To fully understand and appreciate the Laboratory Project Selection Process it is first necessary to establish and define the Aircraft Systems Synthesis concept. To define Aircraft Systems Synthesis, it is necessary to use the classical definitions of *analysis* and *synthesis*. Consider a process, or system, or plant with inputs and outputs. If the process and inputs are well defined, then *analysis* means that behavior of the process is analyzed in terms of outputs. On the other hand, if inputs are given and desired outputs are also specified, then the construction of the system or the process which would yield the desired outputs in view of the given inputs constitutes the *synthesis* process. Aircraft Systems Synthesis, then, means the construction of the Army Aviation R&D Program (process), given the AVRADCOM mission and resources

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(inputs) to yield future airmobile systems and technologies (outputs). The following diagram, figure TI–5, portrays this Aircraft Systems Synthesis concept.

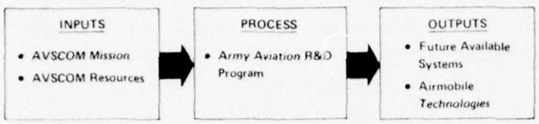


Figure TI–5. Aircraft systems synthesis concept.

Project selection is that portion of the Aircraft Systems Synthesis concept which is directed to effect a balanced R&D program. Other activities of the Aircraft Systems Synthesis are found in the Aircraft Systems Synthesis section (SY) of the Plan.

Development of the project selection process requires some type of rational, systematic procedure containing the necessary elements of aircraft systems synthesis concept; that is, objectives, priorities, and rationale (OPR); and resulting in the form of the major Laboratory thrusts (see individual technology sections for OPR major program thrusts pertaining to that technology).

APPROACH

The following objectives are desirable attributes in the design of a methodology for the project selection process:

- The system must be amenable to the incorporation of both quantitative and qualitative variables.
- Input requirements should rely primarily on data currently available or required for other management activities. Time requirements to provide additional data should be low.
- The methodology should be capable of providing for the processing of nonlinear benefit/cost relationships, identifying differences of opinion, conducting sensitivity analyses on data inputs of greatest uncertainty, and permitting rapid reassessment when key parameters change.
- A mathematical model capable of handling R&D planning inputs whose mechanisms are necessarily based on subjective judgments with considerable uncertainty should be developed. The model's analytical properties should be readily understandable by management.
- The use of the methodology should promote participative management.

The project selection process is the means to provide Laboratory management with the guidance necessary to properly tie the planning and programming to budgeting. The budget process is a recurring one in which the Laboratory and its Headquarters AVRADCOM and DARCOM are involved. The cycle begins with a 5-year funding guidance document, the Command Schedule. Upon receipt of the Command Schedule, the Laboratory prepares proposed programs and plans for a 3-year period (AMC Form 1534 – RDTE Program Data Sheet and DD Form 1634 – Research and Development Planning Summary) in response to the guidance document. These programs and plans are then submitted to DARCOM through AVRADCOM for review. Guidance (AMC Form 1006 – Program Directive/Program Change Request) from DARCOM is issued which constitutes expected funding for the next fiscal year. Proposed programs (AMC Form 1006A – Program Directive/Program Change Request) are then prepared by the Laboratory; they detail specific efforts to be undertaken in view of this guidance. The cycle is repeated each fiscal year with the issuance of a new Command Schedule.

APPLICATION

The development of the Laboratory Project Selection Process requires:

- Clear definition of fundamental laboratory technical objectives
- Priority of these objectives
- Rationale supporting the technical thrust (effort)

For each of the Laboratory's airmobile technology disciplines, a set of objectives, priorities, and rationale (OPR) have been developed and are presented in the program section for each of the technology disciplines (Aviation electronics and manufacturing technology are excluded because the Research and Technology Laboratories is not the lead organization for these efforts).

Each technology is subdivided into a set of subdisciplines, and near-term technical objectives are developed and stated. Additionally, vehicle subsystems elements pertinent to the particular technology discipline are identified. There is an interdependency

between technical objectives, subdisciplines, vehicle subsystems and eventual system effectiveness. The ideal process would be one in which the technical objectives could be quantitatively related to incurred cost and to effectiveness. In lieu of the quantitative ideal, technical thrusts with a priority ranking can be developed. Each technology is reviewed in terms of three considerations, that is, technical subdiscipline, vehicle system, and system cost/effectiveness. The life cycle cost (LCC) model as shown in table TI–A and the system effectiveness elements as outlined in table TI–B are used in this process. The subdiscipline and vehicle subsystem elements depend on the technical discipline. The near-term technical objectives are considered in terms of the cost/effectiveness elements, and a subjective judgment is rendered to rank the near-term objectives. The subdisciplines, vehicle subsystems, and the cost/effectiveness elements are then prioritized independently. From an assessment of the priority listings and the relative ranking of the objective, the technical thrusts for a particular discipline are developed.

As an example, consider the aerodynamics discipline shown in table TI–C. An assessment of that table and the near-term objectives indicates that the first priority major thrust in aerodynamics technology is consistent with the first and second objectives listed (achieve ±10% accuracy in the prediction of overall dB level of aerodynamically-generated noise and reduce this noise by 15% and achieve 20% improvement in predictability of stability and control characteristics) and is aimed at improving the survivability of aircraft systems to make them more effective. If an aircraft is not survivable, all other aspects of life cycle cost are relatively insignificant. In addition to surviving in a combat environment, an aircraft system must be effective; flight controls, dynamics,

TABLE TI–A
LIFE CYCLE COST MODEL

Life Cycle Cost ($)	=	**Development ($)**
		+ Flyaway ($)
		+ Maintenance ($)
		+ POL ($)
		+ Logistical Support ($)
		+ Attrition ($)

TABLE TI–B
SYSTEM EFFECTIVENESS ELEMENTS

VEHICLE	MISSION
• Performance/Mission Requirements	• Mobility
	• Intelligence
• Safety/Survivability	• Firepower
• Reliability/Maintainability	• Combat Service Support
• Human Factors	• Command, Control and Communication

TABLE TI–C
PRIORITIZED AERODYNAMICS OPR ELEMENTS

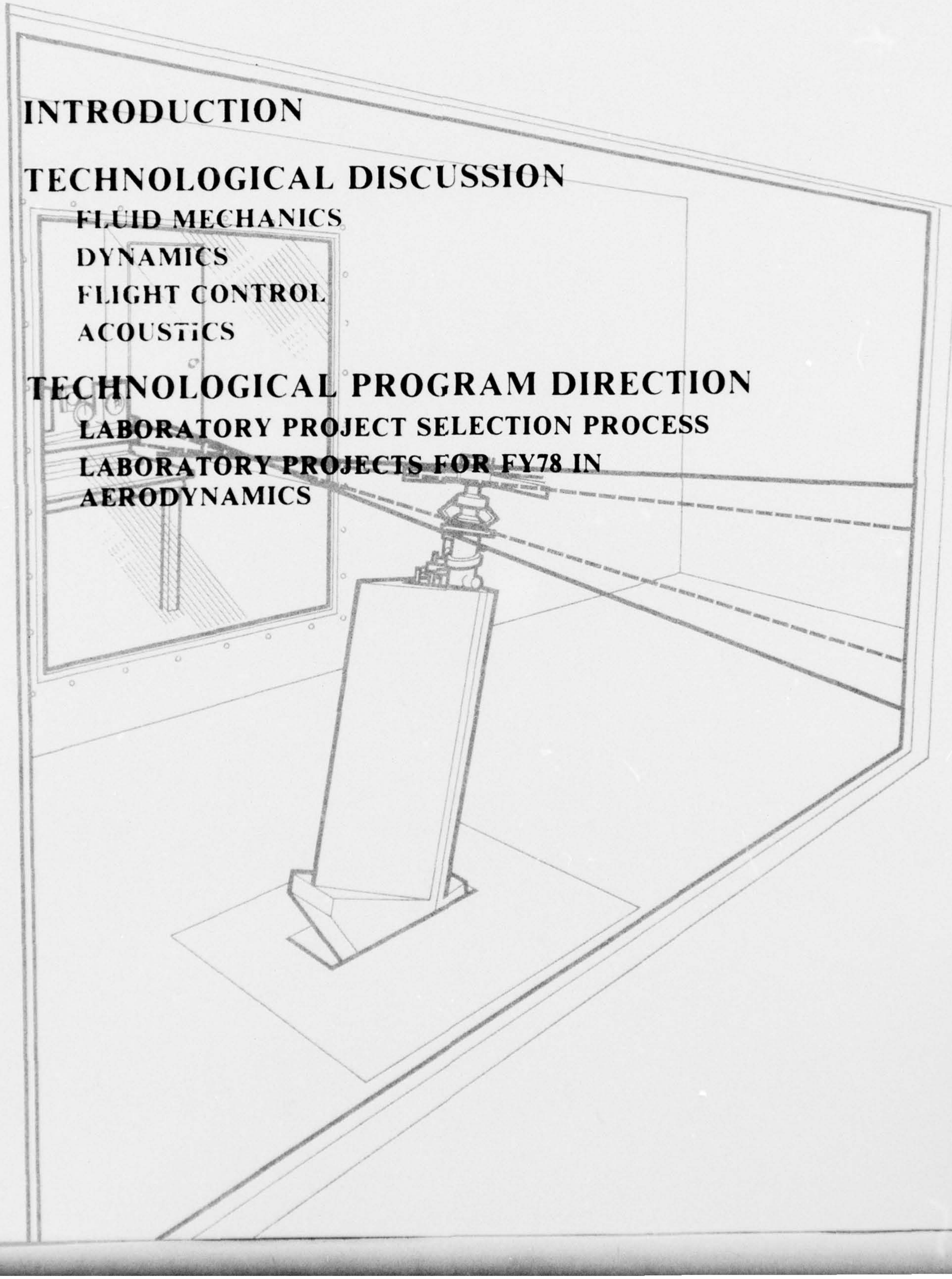
TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Fluid mechanics	I	• Main rotor	I	• Survivability	I
• Dynamics	II	• Tail rotor	II	• R&M cost	II
• Flight control	III	• Flight controls	III	• System cost	III
• Acoustics	IV	• Fuselage	IV	• System volume	IV
				• Fuel efficiency	V

and performance characteristics are all tailored to produce a cost effective system. Each one of these elements is necessary to developing systems with acceptable life cycle costs, and the Laboratory thrusts are developed to provide aerodynamics technology that will result in the highest payoff in system cost in the shortest elapsed time.

RESPONSIVENESS TO SCIENCE AND TECHNICAL OBJECTIVES

The key driver of the Laboratory Project Selection Process is the development of Laboratory R&D objectives from which the individual technology objectives are derived. This is a formidable task for Laboratory management, even for the near-term time period; forecasting for a 20-year period is extremely difficult. These objectives address the near-term and long-term R&D activities that are required for achieving the Army objectives and material needs for which AVRADCOM is responsible. To the maximum extent possible the Laboratory objectives are specifically responsive to the following Army R&D guidance:

- Catalog of Approval Requirements Documents (CARDS), July 1973 (SECRET).
- DARCOM Management by Objectives (MBO) Goals.
- Science and Technology Objectives Guide, FY78 (STOG–78) (CONFIDENTIAL).


INTRODUCTION
TECHNOLOGICAL DISCUSSION
FLUID MECHANICS
DYNAMICS
FLIGHT CONTROL
ACOUSTICS
TECHNOLOGICAL PROGRAM DIRECTION
LABORATORY PROJECT SELECTION PROCESS
LABORATORY PROJECTS FOR FY78 IN AERODYNAMICS

INTRODUCTION

The aerodynamic technology area encompasses four major subdisciplines: fluid mechanics, dynamics, flight control and acoustics. These subdisciplines are generally described as follows:

- *Fluid Mechanics.* A collection of techniques that allow for the prediction and improvement of aircraft performance capability, efficiency, and for steady and unsteady aerodynamic loads on aircraft components.
- *Dynamics.* A collection of techniques that allow for the prediction of time-dependent responses (i.e., deflection, velocity, and acceleration) of rigid and elastic bodies subjected to various forms of excitation including aerodynamic forces and moments. Dynamic response predictions are used to determine system stability, vibration levels, aeroelastic divergence margins, and fatigue loads.
- *Flight Control.* A collection of techniques that allow for the prediction of the capability for stabilizing and controlling the motion of a flight vehicle along a desired path. These techniques encompass control theory, control elements, stability and control, and handling qualities that are used to enhance task performance, extend vehicle operational capabilities, improve safety and survivability, and reduce training needs.
- *Acoustics.* A collection of techniques that allow for the prediction of noise characteristics, both internal and external to the vehicle producing the noise, to determine the source of various components of the noise, and to determine criteria for maximum acceptable noise levels in terms of annoyance and detectability. With noise sources identified, possibilities for reducing vehicle noise can be systematically explored.

The ability to predict aerodynamic characteristics accurately is fundamental to the design of cost-effective V/STOL aircraft systems, since these characteristics affect every facet of the design synthesis process. First, the vehicle empty weight fraction is predicted on static and fatigue loads and on aeroelastic margins that are primarily due to aerodynamic phenomena. Second, fuel requirements are directly related to lift-to-drag ratio. Third, installed power requirements are dictated by the combination of empty weight, fuel weight, and takeoff lifting efficiency – all of which depend on vehicle aerodynamics. Fourth, the handling and ride qualities (i.e., stability, control, and vibration), are a direct result of aerodynamic forces and moments that must be isolated or properly controlled. And, fifth, acoustic properties are a function of aerodynamic configuration and loading which affect external noise and detectability as well as internal noise and passenger comfort.

The aerodynamics portion of the Army Aviation RDT&E Plan, as well as resulting R&D programs, will, for the foreseeable future, be largely concerned with isolating and alleviating those deficiencies of rotary-wing aircraft that currently limit their operational capabilities. Over the years, rotorcraft advancements have been impaired by an incomplete understanding of the highly interactive, unsteady aerodynamic environment of the rotor. While production demands have necessarily given rise to semi-empirical analyses, followed by incremental extrapolations in design, there remains a great need for detailed investigations that further serve as guidance for the theoretician in developing more accurate analytical models. There is also a great need to integrate these analyses into a common system to aid understanding of the aerodynamic and dynamic interactions on the total aircraft.

Of the aerodynamics related phenomena that require further research, those in table AE–A represent the greatest challenges in contemporary rotary-wing aerodynamics. These phenomena are discussed in the appropriate subdiscipline areas and form the basis for the major aerodynamics objectives and thrusts to be presented.

Although emphasis has been placed on rotary-wing research, theoretical mastery of this complicated flow field will inevitably affect the analytical treatment of all other V/STOL flow environments where compressibility, unsteadiness, three-dimensionality, wake interaction, aeroelasticity, and control are important.

Regardless of the level of endeavor (i.e., basic research or applied technology), areas of investigation and program goals must be somewhat configuration-oriented and directed toward achieving scheduled field objectives. For this reason, all R&D activities in aerodynamics have been categorized under the subdisciplines listed as in table AE–B.

TABLE AE–A
UNMASTERED AERODYNAMICS PHENOMENA

FLUID MECHANICS	• Performance prediction techniques • Rotor wake • Stall and separation phenomena of rotor blades and fuselages • Aerodynamic interference between rotating blades and other components • Low speed flight characteristics
DYNAMICS	• Dynamic stability of highly coupled aeroelastic multi-degree of freedom systems • Rotorcraft vibration • Prediction of rotor loads
FLIGHT CONTROL	• Determination of overall handling qualities and control response characteristics • Development of handling qualities criteria
ACOUSTICS	• Impulsive noise • Noise phenomena of fluctuation pressures

Within each major discipline area, quantified achievement estimates have been established as presented in chart AE–I through AE–IV located in the appropriate subsection. Incremental achievement goals are shown for the 20-year span covered by the Plan with application on near-term, mid-term, and future airmobile systems.

It should be borne in mind that there is considerable interdependence, not only among the various categories addressed in aerodynamics, but also among the various disciplines discussed separately in this document.

TECHNOLOGICAL DISCUSSION

FLUID MECHANICS

GENERAL

Numerous techniques have been advanced for describing the flow through the rotor disc and for predicting blade airloads and performance. The aerodynamic phenomena listed in table AE–A are representative of the factors that contribute to the complexity of this flow field. Reliable calculations of the influence of these phenomena on aerodynamic loads are essential, not only for assessing the effects of parametric changes on the performance of Army aircraft, but for defining valid operational limits, establishing structural and propulsion requirements, and making realistic trade-off analyses.

Although recent evaluations of state-of-the-art methods for predicting rotor loads and vibrations show significant improvements in accuracy and reliability, these methods do not yet meet the demands of modern Army aviation. Overall aerodynamic characteristics of conventional helicopters, such as total rotor lift, drag, and power requirements, can be estimated reasonably well, but not the blade-element or component airloads that contribute to stresses, vibrations, and aeroelastic instabilities. Also, the ability to predict some of the overall characteristics of many advanced configurations remains suspect. Therefore, improvements are needed. Additional needs include an examination of the existing methods for defining the sources of the deficiencies and an estimation of the degree of sophistication and rigor that will ultimately be required to model correctly the rotor wake, boundary layer, and separated flow regions. These phases of research should include specially designed experiments to verify the authenticity of mathematical models. The overall intent of such an investigation is twofold: first, to provide the design engineer with reliable bounds on the utility and applicability of existing prediction techniques; and second, to disclose areas of weakness that require further theoretical development.

TABLE AE–B
AERODYNAMICS SUBDISCIPLINE DESCRIPTION

FLUID MECHANICS	• ROTOR AERODYNAMICS Prediction and reduction of vibratory airloads of aircraft components, including blade stresses, control loads, and aerodynamic excitation of noise, vibration, and structural dynamics. • PERFORMANCE Prediction and improvement of aircraft flight capabilities, including hover, rates of climb, cruise and maximum flight speeds, autorotation, and maneuvering flight load factors. • EFFICIENCY Prediction and improvement of aerodynamic drag characteristics, including power requirements in hover and forward flight, fuel consumption, and payload fractions.
DYNAMICS	• AEROMECHANICAL STABILITY Pertains to the prediction of stability characteristics of the coupled rotor-fuselage dynamic system under the influence of self excited aerodynamic, elastic and inertial forces. • AIRCRAFT VIBRATION Pertains to the prediction of structural response of the aircraft due to aerodynamic and inertial excitations, including means for reducing vibration with external devices or by tailoring structural properties. • ROTOR LOADS Pertains to the prediction of loads and stresses experienced by the rotor blades, hub, and control system. • AEROELASTIC TAILORING Pertains to explicit selection of aeroelastic design parameters to produce inherent rotor aeroelastic response which will bring about improved operational characteristics (i.e., performance, loads, stability, etc.).
FLIGHT CONTROL	• CONTROL THEORY Encompasses the theoretical techniques which provide the basic understanding, insight, and computational tools supporting flight control analysis. • CONTROL ELEMENTS Is concerned with development of components of the flight control system to make them less costly, lighter, more reliable, simpler to maintain while maintaining or improving performance. • STABILITY AND CONTROL Covers the information and tools required to support the flight control design synthesis process. Flight control requires significant inputs from the fluid mechanics and dynamics technologies. • HANDLING QUALITIES Describes the characteristics which define the pilot's ability to perform a given task and the workload involved. Stability and control and display characteristics are the primary factors of concern.
ACOUSTICS	• AERODYNAMIC NOISE CONTROL Pertains to the prediction and alleviation of external and internal noise levels produced by: Impulsive waves originating on rotor blades and propellers Strong interactions between the rotor's wake (tip vortices) Inflows turbulence and local blade stall Also pertains to methods of reducing the adverse effects of noise through: Flight path control Development of quantitative detection criteria • INTERNAL NOISE Pertains to those methods of isolating the crew and passengers from the noise levels of operational helicopters.

ROTOR AERODYNAMICS

Unlike the flow field of an airplane wing, the rotor wake remains in the vicinity of the aircraft for a relatively long time, especially at low speeds and in hover, thereby influencing the overall aerodynamic environment of the helicopter. The rotor wake can have a critical effect on rotor aerodynamics, fuselage aerodynamics, download, and indirectly on rotor and fuselage vibrations. It has been recently determined that the rotor wake is a primary factor contributing to inaccuracies in 2.75-inch rocket firings. Additional R&D efforts are required in:

- Modeling forward-flight wakes
- Modeling the viscous tip-vortex formation
- Improving experimental techniques (especially laser velocimeters)
- Studies of wake-fuselage interactions
- Main and tail rotor interference effects

The investigations should be conducted through a balanced program of analytical and experimental studies. Special wake problems involving advanced configurations such as the ABC, Variable Geometry Rotor, or advanced tip shapes should be emphasized. One of the most promising areas for reducing the vibratory airloads and noise associated with the non-uniform, unsteady vortex wake involves the reduction of the peak velocities within the tip vortex. This can be done by changes in the planform or twist of the rotor blades in the tip regions, or by devices that alter the formation and structure of the trailing vortices. Such devices are also being considered for alleviating the vortex wake of large, fixed-wing aircraft. Vibratory aerodynamic loads may be reduced by actively controlling the blade pitch angle through higher harmonic control, or by actively controlling the blade lift, using circulation control concepts. These methods attempt to compensate directly for the large velocity variations and non-uniformities in the wake experienced by rotor blades in forward flight.

Rotor Blade Stall. Boundary-layer separation and stall have a major effect on both performance and vibrations of rotary-wing aircraft. Classical, thin boundary-layer theories with relatively mild inviscid interactions must be broadened from fixed-wing technology to rotary-wing application. New criteria accounting for unsteady turbulent effects, dynamic separation boundaries, and viscous reversed flow regions must be investigated and developed. Beyond this, assessment of large regions of detached flow must be made, since the complete stall and reattachment process affects on rotor performance. Additionally, moment stall, lift stall, and reattachment must be included as separate dynamic events, with each representing important forcing functions on the aeroelastic behavior of the rotor in forward flight.

Unsteady aerodynamic effects have been shown to produce stall delay, thereby increasing the maximum lift coefficient above that for static stall. However, this favorable characteristic may be accomplished by negative aerodynamic damping during this pitch oscillation through stall. This negative damping is caused by a hysteresis in the blade pitching moment, as the angle-of-attack cycle is closed, which can cause dangerously large torsional blade deflections and correspondingly large control loads. This event currently represents a major design limitation of some rotary-wing aircraft, restricting flight speeds to values below available engine power and below the allowable limits of other constraints.

Considerable improvements in estimates of rotor vibratory airloads have been made in recent years by applying empirical corrections, derived from oscillating airfoil tests, to the static stall characteristics of rotor airfoils. Often, however, predictions are still unsatisfactory, and some of the fundamental mechanisms of dynamic stall, especially in the three-dimensional rotor environment, are still not understood. An important feature has been found to be the shedding of a vortex-like disturbance from the leading edge region. Current assessments indicate that this phenomenon can and should be studied in greater detail to provide complete documentation of select cases for guiding and evaluating future theoretical developments.

Once the mechanisms responsible for separation and leading-edge vortex shedding during dynamic stall have been identified, the potential of both static and powered boundary-layer control devices should be investigated. It is conceivable that properly designed fixes on the rotor could delay the onset of separation or sensibly soften the effects of moment and lift stall, thereby reducing vibratory control loads and improving performance, stability, and controllability.

Advanced Blade Tips. Flow models and numerical analysis are both required for inviscid flow investigation at the tip regions of rotor blades. At this location transonic effects, tip vortex formation, and

initial rollup add to the complexities of the highly three-dimensional flow field and often result in disproportionate increases in vibration and rotor power. Existing lifting line methods, which seldom predict correctly either the induced drag or the profile drag in the tip regions of highly loaded rotors, result in errors in performance calculations. Improved inviscid methods using lifting surface theory are needed. Improved inviscid analysis coupled with three-dimensional boundary layer methods may allow assessment of the near-field trailing vortex field and, therefore, the blade vortex interactions. Advanced numerical techniques must be developed to solve the unsteady viscid-inviscid problem interactively. This would provide a rational basis for trade-off optimization of tip shapes with respect to drag and noise.

PERFORMANCE

Advanced Airfoil Section. Advanced airfoils have contributed to performance improvements in the current generation of helicopters. A program is required to extend these improvements by designing and evaluating new airfoils for both specific and general rotor configurations. The airfoil design should permit reductions in rotor profile power and reductions in induced power by permitting advantageous use of blade twist and planform distribution.

The mathematical and experimental techniques for airfoil design must be continually upgraded to minimize the experimental efforts required in the airfoil design process. For example, the mathematical models need improvements in both static and dynamic stall prediction capability.

Airfoil characteristics data from wind-tunnel tests must be made available to permit rotor design and performance predictions in mathematical models. These data must define the aerodynamic characteristics for the operating range of angle of attack and Mach number at Reynolds numbers corresponding to both full scale and experimental model scale conditions. The data should include dynamic stall characteristics and should be referenced to a selected baseline airfoil to permit evaluation of incremental performance gains.

Fuselage and Hub Aerodynamics. Rotorcraft shapes have largely been a matter of empirical design, primarily because of an inadequate understanding of rotor flow field. Without experiment, vehicle drag predictions can be in error by as much as 50 percent. Estimates of rotor form drag are also deficient because of inaccurate assessments of compressible effects and boundary-layer separation. As configuration size and complexity increase, methods that realistically account for download will become crucial in determining hover power requirements. Methods to predict hub drag, which can account for over 50 percent of aircraft flat plate drag in forward flight, are likewise important for accurate predictions of power required and maximum speed.

Aerodynamic drag represents wasted energy. Significant reductions in fuel consumption of contemporary helicopters could be achieved by reducing hub drag, separation-induced drag on the helicopter fuselage, form drag on protuberances, and drag due to unfavorable interference between the main rotor and other components of the aircraft.

In addition to the fuselage drag, the lift, sideforce, and the rolling, yawing, and pitching moments are critical in determining the stability and control characteristics of the configuration. At present, large scale wind-tunnel testing is the only reliable technique available for determining the forces and moments on the fuselage, especially when large regions of separated flow are present. Improvements in analytical tools should therefore be coupled with experimental investigations in order to enhance the accuracy of the predictions.

Aerodynamic Interference. Interactions between rotor wakes and fuselages (or between separate rotor wakes) produce vibrations and adversely affect aircraft lift and drag, thereby degrading performance. It has been shown that fuselage-to-rotor interference can increase local blade angle of attack by as much as 10°, resulting in blade stall and increased vibration. Flow interference can also introduce extraneous forces affecting stability and handling characteristics. Another problem is the loss in yaw control that can occur when the wake of the main rotor passes through the tail rotor. Studies have led to relatively simple modifications to existing aircraft, such as reversing the direction of rotation of the tail rotor. This technique was used to partially alleviate severe problems that were being encountered by operational aircraft. A search for a better fundamental understanding of the phenomenon should be continued and more efficient configurations developed. The V-tail, currently under investigation is one such configuration that shows promise.

Flight Path Modeling. To avoid use of expensive or dangerous flight testing, analytic models must be developed to allow prediction of flight paths in maneuvering flight. These flight path models aid in developing flight techniques and emergency procedures based on aircraft performance. Flight path modeling allows study of configurations not yet built or variations of current vehicles.

Autorotation and low-level flight are areas in which flight path modeling aids in reducing the risks inherent in developing new performance procedures. The designer also needs help in reducing the large number of alternative configurations to a few that show the greatest promise of providing a given performance objective. To account for new developments or ideas, flight path modeling must be kept apace with the state of the art of helicopter design.

EFFICIENCY

Prediction Procedures. The increasing spiral in aircraft size, sophistication, and cost (as well as the projected efficiency and cruise-speed trends shown in figures AE–1 and AE–2) place great importance on

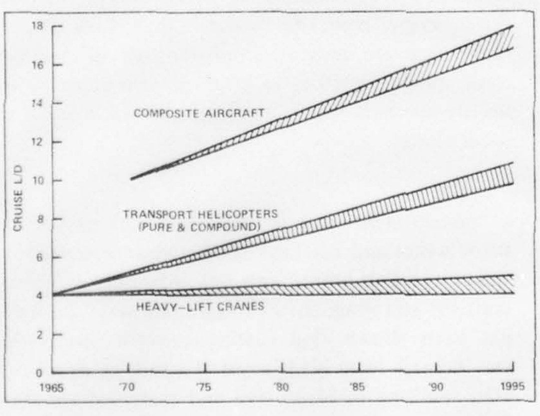


Figure AE–1. Aerodynamic efficiency trend.

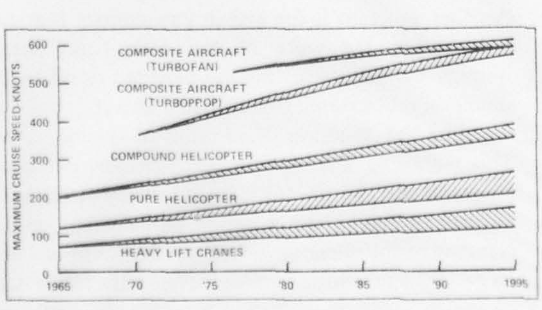


Figure AE–2. Cruise speed trend.

the ability of the designer to define accurately performance and trade-off limits of a system in early conceptual studies. The feasibility of a particular system could hinge on such an analysis. Available prediction techniques are considered inadequate for this task; the result is erroneous estimates of cost and performance that could lead to unjustified departures from demonstrated design concepts.

Considerable effort is needed in a comprehensive analytical treatment of the rotor flow field. Care must be taken to avoid building a theoretical model from unproven fragments or a model of unwarranted complexity. Specifically, initial attempts should be focused on describing a two-dimensional airfoil that oscillates through stall, thus encompassing unsteady laminar and turbulent boundary-layer effects, regions of separation, and viscous-inviscid interactions. With the assurance of experimentally demonstrated reliability, attaining this level of analytical competence alone would qualify as a major contribution. Other phases should address more complicated three-dimensional flows, such as would exist on rotating finite-span airfoils.

Configuration Optimization. Specialized areas of research must be integrated so that resulting criteria can be used in optimizing the overall V/STOL configuration for specific mission requirements. For example, all airmobile systems would benefit from improved high-speed effectiveness and increased agility. This is especially true for advanced attack helicopters which require dash speed and rapid nap-of-the-earth maneuvering capabilities for survival. High cruise speed tailoring increases the productivity of a system that must be capable of swift troop delivery, weapons support, or evacuation, as is the case for transport type aircraft. With increasing forward speed, the conventional rotor becomes progressively less efficient in producing useful thrust, either for lift or propulsion. In addition, it suffers from problems related to stability, gust sensitivity, and noise. A general demand for higher speed, heavier loads, and longer ranges, combined with the desire to retain low disc loading characteristics in hover, has encouraged the development of compound vehicles. By adding a fixed or pivoted-wing, the forward flight lift requirement of the rotor is relieved. However, the apparent performance gains brought about by compounding are counterbalanced by increased initial costs, structural weight, and complexity. Other possible concepts include a variable-diameter rotor and a selective blade feathering system. Numerous advanced [illegible]

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being explored that may contribute considerably to improved VTOL versatility in achieving combat superiority. However, to realistically establish their feasibility and potential, these concepts must be incorporated into a flight vehicle. See section AT, Advanced Technology Demonstration, for a discussion of ongoing programs that fall within this category.

Supplementary Aero Devices. Another important aspect of aerodynamics research relates to the addition of supplementary static and power-augmented control, lift, and propulsion devices. Various performance-increasing techniques, including drooped leading edges, slots and slats, and numerous types of flap arrangements, have been applied to fixed-wing geometries. These methods, which depend solely on free-stream energy diversion, have met with considerable success. Alternative systems have been designed to convert propulsive exhaust energy into useful lift and control energy. The benefits of a compound configuration employing assorted types of variable-geometry fixed and pivoted wings, with and without additional blowing and thrust diverting devices, need to be investigated. The program should include techniques for predicting the performance and stability characteristics of these systems in order to establish their feasibility before proceeding with technology demonstrations.

FLUID MECHANICS TOPICS SUMMARY

The various research topics discussed under fluid mechanics can be categorized as shown in the listing in chart AE–I. Quantified achievement goals are also indicated in the chart.

DYNAMICS

GENERAL

The importance of a thorough and comprehensive understanding of the dynamic characteristics of aircraft in general and of helicopters in particular has been appreciated in varying degrees by designers for some time. It has long been realized that dynamic characteristics can determine the fate of rotary-wing aircraft. Unfortunately, however, in several instances the importance of dynamics in Army aircraft has been recognized so late in the design process that finding the required solution to the resulting problems has been extremely costly. In other instances, the problem may be recognized but the limitations of state of the art compel the designer to place operational constraints on the aircraft rather than provide a design solution that would eliminate the problem from the aircraft's originally intended flight envelope. For example, almost without exception, the limiting factor on the top speed of helicopters is not an installed power limitation, but excessively high vibratory loads that increase with forward speed. When the significant role that dynamics plays in the design of rotary-wing aircraft is considered in relation to the fact that the Army's aircraft inventory is largely rotary wing, it becomes obvious that recognition of aircraft dynamics in the formulation of an Army air mobility research and development program is of highest import.

Recognition of the importance of and the need for dynamics research for the development of improved Army aircraft is the first step in establishing a practical plan for executing that research. The next step is recognizing and appreciating the tremendous complexity of the problem. Figure AE–3 represents the dynamics design problem that includes all the elements of the rotorcraft including the pilot and control system. As indicated, the rotor blades are elastic members and have many coupled modes within themselves. They, in turn, are attached, through flexible linkages and a flexible swashplate, to the remainder of the structure, which is represented by a series of elastically coupled lumped masses. All the degrees of freedom shown are excited continuously by periodic inertial forces and by complex aerodynamic loadings, represented in the figure by the hammer.

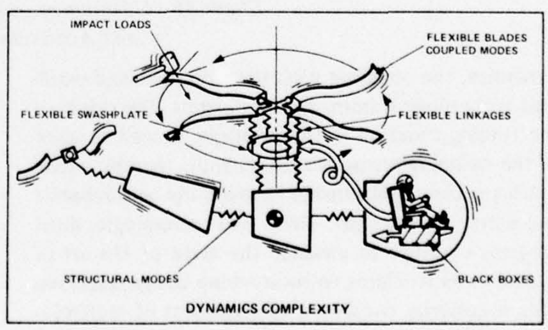


Figure AE–3. Dynamics complexity.

From figure AE–3 it is obvious that the dynamic problem is strongly coupled with other technologies, particularly materials, structures, and aerodynamics. Recognizing that the dynamic problems involved relate to structural dynamics as opposed to rigid-body

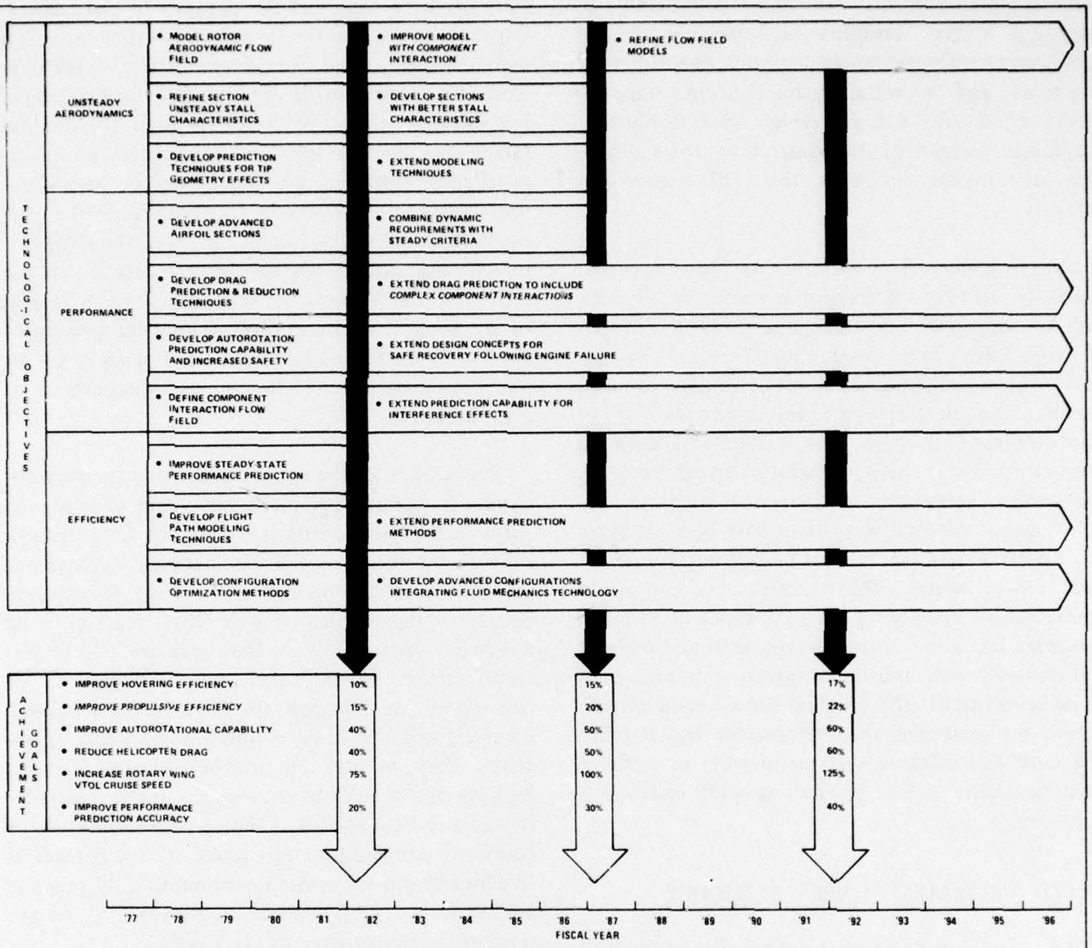


Chart AE–I. Summary of Fluid Mechanics Objectives and Achievement Goals

dynamics, the coupling with the structures and materials technology is immediately obvious. The origin of the forcing function in the problem, as well as some of the damping terms, is aerodynamic, thereby necessitating a close relationship between the aerodynamic and dynamic programs. These two technologies must progress together to advance the state of the art of dynamics as it relates to rotary-wing design analyses. This necessarily combined advancement of technologies is illustrated in figure AE–4, which is a summary of the present capability and of what current efforts are expected to accomplish with respect to the capability for making combined aerodynamic-dynamic analyses. The first boundary in the figure represents a judgment of where current capabilities lie in terms of handling the combined aerodynamic and structural dynamic effects. The second boundary indicates analytical and experimental studies under way that will improve these capabilities. These relate to inflow effects in the aerodynamics and rigid-body and elastic degrees of freedom of the rotor and fuselage in the structural dynamics.

The need for an organized effort to advance the state of the art in dynamics is obvious. Key factors related to each of the Army air mobility missions have been addressed in the Systems volume of this document. An inspection of these key factors reveals that there is not a direct relationship between any one factor and a basic science area such as dynamics. Rather, advances in dynamics have indirect effects such as reducing life-cycle cost. Reduced life-cycle cost is a result of improved reliability and maintainability techniques and procedures. A significant factor

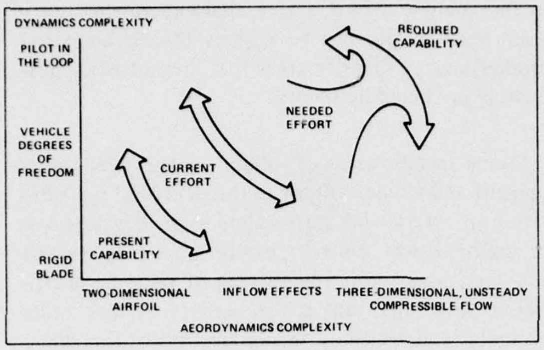


Figure AE–4. Aerodynamic and dynamic considerations required in design analysis.

in improved reliability and maintainability of rotary-wing vehicles is the alleviation of the dynamic loads inherent in these aircraft. The achievement of this objective is expected to be a direct consequence of the R&D effort presented in this portion of the plan and thus relates to the key factor of low life-cycle cost. In a similar way, the objectives of the R&D program in dynamics are related to each of the key factors shown.

The program presented herein is bas[illegible] three major areas that constitute rotorcraft [illegible]: aeromechanical stability, aircraft vibration, and rotor loads. In the following discussion of each of these areas, a general description of the technology is given, subjects needing research are identified, and goals are defined for potential practical improvements of future helicopters.

AEROMECHANICAL STABILITY

Aeromechanical stability concerns the inherent tendency of structural motions to grow or subside. Unless all such motions are positively damped, unacceptable limit cycle vibrations or catastrophic structural failures will result. The technology of aeromechanical stability is aimed at ensuring that all potential instabilities are avoided during development of new aircraft and that no instabilities appear as a result of operational changes or normal deterioration of the aircraft. This technology is also concerned with minimizing the adverse side-effects of techniques used to prevent instabilities. The research program in aeromechanical stability comprises several general objectives including the following: developing and verifying analytical methods for predicting potential instabilities; defining and describing the behavior of complex rotor configurations with respect to the important system parameters; and identifying ways to eliminate instabilities or to minimize the adverse effects of eliminating them.

A basic class of instabilities concerns the dynamics of isolated rotor systems. Classical blade flutter is usually amenable to existing analytical techniques. A potential benefit in this area is a reduction of the weight penalty that is usually incurred by flutter prevention mass balancing. Another type of instability, involving the coupled pitch, flap, and lead-lag motions of the rotor blade, is especially important for hingeless rotor configurations. This phenomenon is dependent on a large number of rotor blade parameters and is not yet well understood. Stall flutter is another serious problem for many rotor types in high-speed forward flight because it produces excessive vibratory loads that are transmitted to the rotor control system. Another type of rotor blade instability can occur at high rotor thrust conditions during hover, for rotor configurations with a large number of blades. This phenomenon is associated with blade-vortex interactions and may be manifest as an out-of-track condition, a subharmonic limit-cycle oscillation, or a transient vibration. In high-speed forward flight, articulated rotors have exhibited difficulties that are mainly due to excessive rotor flapping sensitivity during maneuvers and operation in atmospheric turbulence. Compressibility effects on the advancing blade tips may produce erratic blade flapping behavior that can seriously affect the rotor control characteristics.

Another class of aeromechanical instability involves the coupling between the rotor and fuselage of the helicopter. Such phenomena as classical ground resonance fall into this category. More recently, similar instabilities have been discovered for hingeless rotor helicopters in flight; these are termed air resonance instabilities. In some instances, air resonance may also occur for tandem helicopter configurations. Coupled rotor-fuselage instabilities at high-speed forward flight conditions are not yet well understood, especially for hingeless rotor helicopters.

Many other rotor instabilities may occur that are not easily categorized but can have important consequences. Rotor-blade instabilities may result from excessively flexible control systems where coupling between the fuselage structure and the rotor can take place. Other related examples are instabilities involving a feedback control system. These are particularly troublesome because they appear as a byproduct of

an attempt to stabilize some other marginal dynamic characteristic of the helicopter – for example, a stability augmentation system intended to improve the vehicle flying qualities. A potential exists for nonlinear instabilities because the basic equations of motion of a helicopter rotor are nonlinear. For normal operating conditions, such systems may be stable, with no indication of potential difficulties. However, when a certain operating condition is exceeded, the system can become unstable. Other dynamic systems subject to instabilities are tail-rotor/fuselage systems and tilt-rotor aircraft; in both, a rotor is mounted at the extremity of a long flexible structure and the coupling of various rotor and structural modes may be responsible for very complex instabilities. A disturbed aerodynamic environment may also be an additional cause for difficulty in these cases.

The complexity of these dynamic problems, which can lead to very troublesome instabilities, places severe demands on dynamics technology. This become especially difficult when it is realized that the objective is to discover and prevent such occurrences before a prototype is developed. If a serious instability is discovered after a prototype has been developed, a major redesign of the dynamic system of the aircraft may be required. Because of the complexity of the dynamic problems, it is important to realize that several key ingredients are required in a long range plan of research. Without these, considerable efforts may be expended without meeting the required objectives. The key ingredients are related to one another; together they will yield a detailed and comprehensive understanding of those dynamic phenomena that are potential causes of instabilities in future aircraft. Without such a basic and comprehensive understanding, potential instabilities will not be reliably predicted.

The key ingredients in the technological effort may be defined as various theoretical and experimental research efforts. First, the complex dynamic system must be broken down into smaller and simpler elements. Only at this level will the mathematical models be simple enough to permit a physical interpretation that will result in a full understanding of the problem. In this way it is also possible to identify and isolate those essential physical parameters that govern the stability of the system. Second, when the basic elements of the system are sufficiently analyzed and understood, they may be combined to describe the complete system. This process depends on the successful completion of each of the individual stages in the analysis. Third, a continual experimental program must be pursued to validate the mathematical models and to identify areas that are not being adequately predicted by theory.

Some specific areas of technology that need development and refinement are in the structural representation of rotary-wing systems and in the development of mathematical tools to handle nonlinear systems and equations with time-varying or periodic coefficients. Also important is the need to develop more accurate experimental techniques both for wind-tunnel models and full-scale aircraft. Improvement is needed in data analysis as well. The experimental measurements generally include random and periodic noise both from the experiment and the measurement process. The effects of this noise must be removed to determine the system stability, a task made more difficult when the experiment includes nonlinear or periodic effects.

One of the difficulties in mathematical models of structural systems of rotary-wing vehicles is in accounting for all of the highly coupled degrees of freedom. The equations for a rotating beam undergoing large deflections are complicated by variable and discontinuous changes in mass properties, stiffness, and torsional rigidity, and they are in turn attached to flexible fuselage structures of considerable complexity. Because some choice has to be made in approximating these structures mathematically, a better understanding is needed of how these structures behave. The special characteristics of new materials such as composites, must be accounted for, especially with respect to defining the structural damping, which may have a strong influence on stability.

The mathematical tools that need to be developed may be fairly well categorized by present knowledge of the basic characteristics of rotary-wing systems. Periodic-coefficient equations are typical for rotors in forward flight because of the oscillating aerodynamic forces acting on the blades. Floquet theory is useful for predicting the stability of these systems; however, little experience with this technique is available for problems with many degrees of freedom. The large structural deformations of rotor blades often make linear assumptions inappropriate and require new techniques for solving nonlinear equations. The method of matched asymptotic expansions is a potentially powerful tool for use in solving many of these problems.

With the ability to generate a comprehensive understanding of the dynamics of rotary-wing systems, aeromechanical instabilities should not pose a threat to the successful development of new aircraft. Thus, it is feasible that all potential aeromechanical instabilities can be avoided and, further, that such instabilities would no longer impose constraints on the practical operational envelopes of rotary-wing aircraft, or incur unnecessary design compromises during development.

AIRCRAFT VIBRATION

Aircraft vibration is the response of the structure to periodic excitation forces. In the case of the helicopter, the response of interest is the fuselage structure, and the main excitation is provided by rotor forces applied at the rotor hub. These forces, in turn, represent the response of the rotor blades to periodic aerodynamic loading. The vibratory response of the fuselage structure is determined by the nature of the applied rotor forces and also the structural dynamic properties of the fuselage. The objective of research efforts is to develop techniques and methods for predicting and minimizing aircraft vibration.

As noted earlier, the limiting factor on a helicopter's maximum forward speed is not installed power, but vibration level. Although it is known that unacceptably high vibration levels exist in some flight regimes, there is not a clear definition of the requirements for the vibration spectrum reduction. Obviously, the eventual goal is to reduce vibration levels throughout the entire flight envelope, but this will not take place in one quantum step and it is important to define those portions of the vibration spectrum that, when reduced or eliminated, will provide the largest payoff in terms of weight and performance. When it has been firmly established what the requirements are, it will become clearer what methods should be pursued in attempting to satisfy them. To date, several approaches have been followed. These include methods to de-tune the vehicle structure to minimize response to periodic aerodynamic loads, development of active or passive devices to isolate or absorb vibratory loads, and investigations aimed at reducing the periodic aerodynamic loading on the rotor.

The periodic aerodynamic loadings arise from unsteady aerodynamics, airfoil dynamic stall characteristics, blade-vortex interactions, and the basic periodic velocity variation experienced by the rotor blade in forward flight. Research efforts aimed at reducing these loadings can be expected to alleviate some of the vibratory load problems on rotary-wing aircraft. Improvements in the dynamic stall characteristics of airfoils and minimization of the tip vortex velocity are probably the most promising areas for reducing these aerodynamic inputs. Other potential methods for reducing periodic aerodynamic loads may result from active control of the blade pitch angle through higher harmonic control, or of blade lift by using circulation control. These methods attempt to compensate directly for the large velocity variations and for the nonuniform-induced velocities experienced by the rotor blade in forward flight.

The traditional method for reducing aircraft vibrations is to design the structure so that natural frequencies are not placed in proximity to the fundamental aerodynamic forcing frequencies. This tuning procedure is only as successful as the accuracy of the methods used to predict the natural frequencies of the structure and those techniques have never been completely reliable for rotary-wing aircraft. The use of advanced composite materials holds promise for tailoring the structure to a much higher degree than was previously possible with conventional materials. This then allows greater potential for tuning the structure to avoid the aerodynamic forcing frequencies, but, in turn, increases the accuracy requirement in the structural modeling methods. As is true for the analysis of aeromechanical instabilities, a successful solution to the structural dynamic approach to vibration reduction must rely on a more comprehensive understanding of the fundamental elements of the problem. This entails mathematical modeling of simplified structures, experimental efforts to validate those analyses and identify areas that are not adequately predicted by theory, and an integrated approach to treating the entire problem.

An effective method of dealing with vibration problems in the past, especially in view of the complexity of the structural dynamics of the complete system, has been to attempt to suppress the transmission of specific vibratory inputs or the vibratory response at specific locations. Thus, a whole series of techniques and devices has been investigated and applied to helicopters with substantial success. These devices or methods may involve active or passive means and are usually characterized by a very narrow range of effectiveness; that is, a particular vibration absorber may be well suited to one type of rotary-wing aircraft but relatively ineffective on another. In

view of the inherent difficulties in the methods discussed previously, the use of vibration isolator systems deserves continued attention, even if only as an interim solution. Efforts should be made to improve their effectiveness, reducing the attendant weight penalty, and increasing the mechanical reliability.

ROTOR LOADS

Rotor loads are considered to include the dynamic loads and stresses existing in the rotor blades and blade pitch control mechanisms. Together, vibratory response and rotor loads usually determine the limiting speed and load factor operational envelope. Furthermore, the rotor loads determine the fatigue life and reliability of rotor system components. The calculation of rotor system loads is one of the most difficult analytical problems of rotorcraft technology because of the importance of nonlinear, unsteady, three-dimensional, compressible aerodynamics, and the complexity of the structural dynamic characteristics of nonuniform rotor blades. The objectives of this area of research are to improve methods for predicting rotor loads and to find ways of reducing rotor loads. The benefits of reduced rotor loads are clear: component life will be increased and costs reduced. Better prediction of rotor loads will permit correspondingly better predictions of aircraft vibration and will facilitate future reduction in vibration levels. The present inaccuracies in predicting rotor loads require overly conservative safety factors in the design of rotor hub and control system components. More accurate predictions will result in more efficient structural design and significant savings in weight.

The technology for predicting rotor loads is still being developed. The problem can be broken into three basic areas: aerodynamics, structural dynamics, and mathematical analysis techniques. The aerodynamic technology, particularly in the case of complex phenomena such as dynamic stall and blade-vortex interactions, is being pursued as part of the fluid dynamics program. The structural dynamics technology involves the description of the elastic and inertial properties of a rotor blade, including the details of the non-uniform, twisted, composite structure. Consideration must also be given to nonlinearities associated with large displacements that occur during extreme operating conditions. Finally, improvements are needed in the mathematical methods used to solve these highly coupled, nonlinear equations. The accuracy of the solutions needs to be improved and computer time necessary to obtain the solutions must be reduced. Until these numerical solutions can be produced at moderate cost, they will only be of limited value to rotorcraft designers. Because of the complex interdisciplinary nature of rotor loads prediction methods, it is difficult to validate their accuracy and determine specific elements that require improvement. Special attention is required to devise techniques for validating the various elements individually, and additional wind tunnel tests of full-scale rotors are needed to determine the accuracy of the final results.

As the accuracy of rotor loads predictions is improved, it will become increasingly practical to use these methods to reduce rotor loads by properly tailoring the structural and aerodynamic properties of the blade. For example, torsional stiffness of the blade has been shown to influence stall flutter and the consequent control system pitch link loads. Other techniques and devices should be investigated to reduce rotor loads. Because of the close relationship between rotor loads and aircraft vibration, efforts in these two areas will necessarily be dependent on each other.

AEROELASTIC TAILORING

Aeroelastic tailoring represents an advanced design philosophy applicable to the development of aeroelastically conformable rotor systems such as the CTR, compliant rotor, live twist rotor, etc. In this design approach, aeroelastic properties will be tailored to bring about a time dependent rotor response that will inherently improve general rotor operational characteristics. These characteristics will include improved dynamic loading, reduced fuselage vibration, improved rotor efficiency, improved aircraft performance, and improved stability and handling qualities. The range of aeroelastic parameters that will be included is quite large and includes:

- C.G. distribution
- A.C. location
- Planform
- Mass and inertia distribution
- Root end fixity
- Control system stiffness
- Fuselage stiffness and inertia properties

Obviously, this is an extremely large range of rotor parameters to study and the study will not be

attempted in one step. Instead, a methodical procedure must be developed to study small numbers and ranges of parameters, as well as limited objectives. Analytical and experimental data already exist that can contribute to such a study and it is important that a well thought-out framework for organizing the problem be defined so that the results of completed and ongoing research can be properly utilized.

The scope of the problem is clearly too large to treat experimentally and it is imperative that an effort be placed on developing analytical procedures that can be used with confidence to provide engineering data that can be used both in designing new systems and in developing future research programs. Existing computer analyses must be used to the fullest extent possible in conducting ongoing research and in the design of aircraft presently being developed. It is necessary to determine the limitations of existing analyses if new analyses are to be intelligently developed. New procedures will be gradually evolved which, when coupled with the results of carefully planned experimental research, will provide the basis for developing advanced aeroelastically conformable rotor systems.

DYNAMICS TOPICS SUMMARY

The various research topics discussed under dynamics can be categorized as shown in the listing in chart AE–II. Quantified achievement goals are also indicated in the chart.

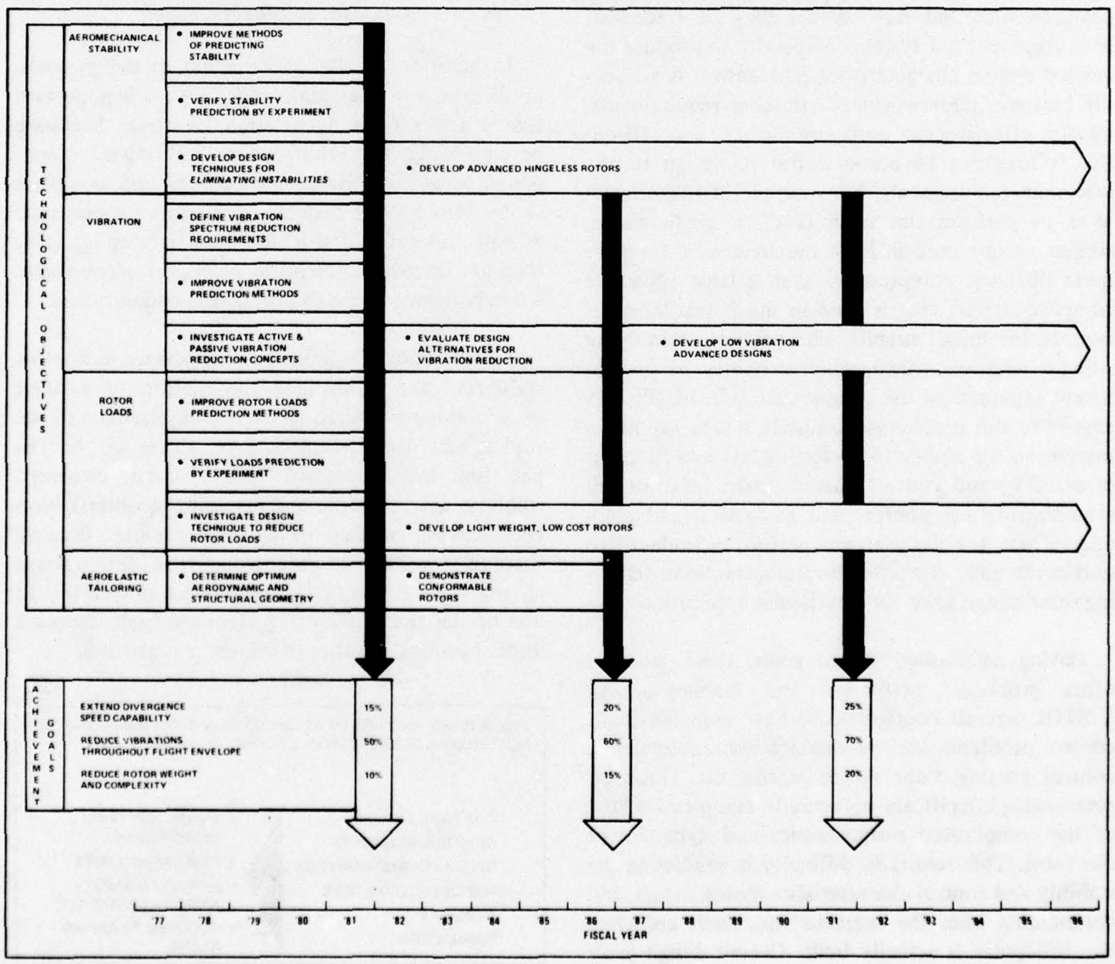


Chart AE–II. Fluid Mechanics Topics Summary

FLIGHT CONTROL

GENERAL

Superior levels of maneuverability, speed, payload, structural integrity, and reliability are of little use if poor flying qualities limit their application. The ultimate objective is to be able to make full use of all the inherent capabilities, that is, to be able to fly to the limits of the service flight envelope under all the desired environmental conditions (wind, turbulence, day, night, limited visibility). There is little doubt that almost any objective can be achieved at a cost. An intractable aircraft, with plenty of control power, can be made well behaved using an appropriate flight control system. Unfortunately this is usually an expensive and unreliable approach. The real question is what are the minimum acceptable basic vehicle characteristics and how should they be traded-off with flight control system complexity to produce the desired system characteristics. The answer is a trade-off between pilot workload, training requirements, mission effectiveness, cost, complexity, and reliability. It may not be cost-effective to design to the minimum requirements. For example, if two aircraft were to perform the same tasks, a small, cheap, simple aircraft used in large numbers would require quite different compromises than a large expensive complex aircraft that is used in much smaller numbers. In the simple aircraft, pilot proficiency in flying will be relatively cheap, whereas it may be prohibitively expensive in the complex aircraft. Ideally, the answer to this problem is to obtain systematic information on the ability to perform a task as a function of stability and control characteristics, and display requirements for control and navigation and guidance. Then, the designer can perform a trade-off to obtain the most cost effective compromise in achieving these design goals for a particular application.

Having established design goals, there are two other problems: prediction and evaluation. All V/STOL aircraft configurations have complex flight control problems, such as stabilization requirements, control phasing, large power effects, etc. However, rotary-wing aircraft are particularly complex because of the complicated aerodynamics and dynamics of the rotor. This results in difficulty in predicting the stability and control characteristics during design, and determining what the characteristics really are when the helicopter is actually built. Overall design goals and evaluation capabilities are the primary topics in this subsection; prediction is treated primarily in the previous subsections. Figure AE–5 is a block diagram of the closed loop pilot-aircraft system that shows the interdependence of aerodynamics, dynamics, and flight control.

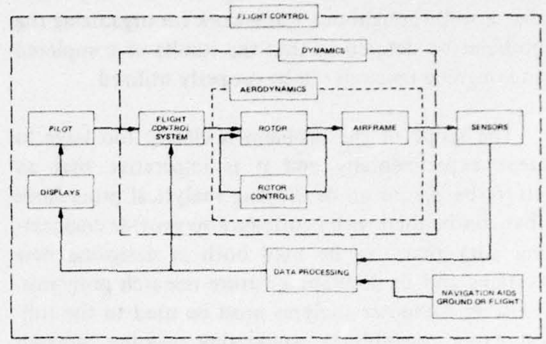


Figure AE–5. Interdependence of aerodynamics, dynamics and flight control.

In addition to the development of design goals, prediction, and evaluation capability, it is important that practicality is demonstrated through hardware development. Everything from individual components, such as fluidic rate sensors and complete fly-by-wire control systems, to aircraft systems such as ABC, tilt rotor, and RSRA need developing. Only then are the real problems in a concept uncovered in a timely manner prior to production commitment.

Flight control is defined as the science and art of stabilizing and controlling the motion of a flight vehicle along a desired path. It comprises the items. topics, and objectives shown on figure AE–6. The first four topics (control theory, control elements, stability and control, and handling qualities) have been chosen as the major subdisciplines. Because there is considerable interdependence and overlap among these topics, subjects that are not clearly in one of the first three categories have been discussed under handling qualities to minimize repetition.

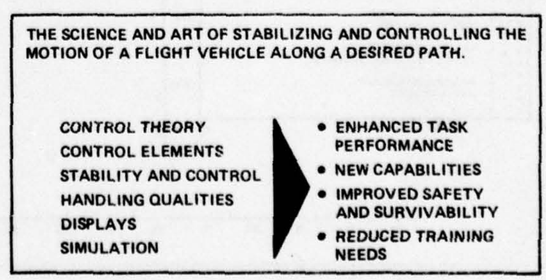


Figure AE–6. Flight control.

CONTROL THEORY

Optimal Control. In recent years, considerable effort has been expended in the development and refinement of techniques in the field of optimal control theory. Such techniques provide a potentially useful and orderly process for the design of control systems, especially for multiple input/output systems. With any technique however, the system is only optimal for a particular configuration, relative to a particular performance criterion. More work is required to investigate and define the performance criteria, and more work is required to assess the effects of those non-ideal characteristics always found in real applications (e.g., measurement noise, plant unknowns, etc.).

Applications of optimal control can conveniently be divided into two aspects: control and guidance. Control aspects are typified by control phasing or blending to give a desired or tailored response. Guidance aspects are typified by determining flight paths to minimize fuel usage or noise exposure. These two will be discussed separately.

Control System Design. Given a well-defined aircraft with adequate control over each degree of freedom, the modern control theoretician can easily calculate the control gearings, control interconnects, and control feedback quantities to obtain any desired response. Unfortunately, real applications do not have all the ideal ingredients. The Tactical Aircraft Guidance System (TAGS) is an example where a step input to the longitudinal control commands a new speed rather than an attitude or attitude-rate. This sounds highly desirable, but there are an infinite number of ways in which the new velocity can be achieved (e.g., a severe initial attitude change to get a large initial translational acceleration, followed by a gradual bleedoff as the desired speed is approached, or an attitude change only large enough to sustain the final velocity). In the latter case, the speed change may take too long and the pilot may have to overdrive. There is need to obtain a better understanding of just what response is suitable for a given task. Ground simulation with simple models is one approach needed here.

The next problem is to achieve these desired responses on non-ideal aircraft. The aircraft will be poorly identified (prediction and evaluation), there will be limited control authority and insufficient control over some degrees of freedom, some states will not be measurable, the sensors that are available will be noisy, and the aircraft will have to fly in turbulence. These are the problems that the control theoretician must solve to convert his theories into useful tools for the control system designer. It is important that work be continued and expanded in this area, with the emphasis always on solving the practical problems, not developing new theories.

Guidance Analysis. The second aspect, guidance, requires inputs from the tactician: How does he want to use his aircraft? To minimize fuel usage during climb, descent, and loiter? To maximize over-obstacle capability? To minimize noise propagation? To minimize exposure to ground fire when approaching a forward landing site? Again, the ideal must be tempered by the realistic; optimum trajectories may not be flyable by the pilot, or may require complex flight-director aids. Since the real pertinence of this work is specific to a particular aircraft and mission, it should be performed at the advanced development (or higher) level in support of a particular system, that is, flight path optimization considerations must be part of the control system design trade-off pertaining to display-pilot workload/training.

Control Theory Summary. The research topics discussed under control theory may be summarized as follows:

- Perform piloted ground simulations to determine desired control laws
- Develop optimal control design techniques for non-ideal plants
- Apply developed optimal design techniques to specific aircraft and missions
- Verify with piloted simulation and flight test

CONTROL ELEMENTS

General. The flight control system provides an interface between the pilot and the airframe. A primary component within this interface is the rotor. Thus, the control system designer must be aware of, and accommodate the needs of, both the dynamics and the flying qualities specialists. Figure AE–5 shows that the control system is as much a part of "dynamics" as it is of "flight control." The brunt of "control elements" is hardware – the development of control system elements, from concept to field application, with the objective of making them cheaper, lighter, more reliable and simpler to maintain, while maintaining or improving performance.

Fly-By-Wire. Initial dependence on pure mechanical systems is giving way to the inclusion of hydromechanical, electromechanical, electronic, fluidic, and optical devices. As aircraft size increases, the potential weight saving in an electronic or optical control system (fly-by-wire) becomes greater. The feasibility of fly-by-wire (FBW) has been demonstrated in several Air Force programs as well as in the Army TAGS program, and the HLH demonstrator. Another potential advantage of FBW is survivability. The redundancy requirements and lightweight connector routings offer potential advantages in survivability from battle damage. This may be particularly applicable to AAH and ASH roles.

Sensors. A program to develop the application of fluidic devices to augmentation systems, using hydraulic fluid as the working medium, has now reached the stage of field demonstration and the potential of high reliability with low cost seems to be realizable. Improvements in sensor designs have significant cost savings potential. For example, many guidance and control systems, particularly those that are self-contained in the aircraft rather than ground-aided, need ground-referenced position information. Unfortunately, gyro-inertial systems are expensive and the gyros have short life in the typical helicopter vibration environment; perhaps the emerging Laser Inertial Navigation System (LINS) will lead to significant cost and reliability improvement. All helicopter roles have as a major flight phase the ability to maintain hover over a spot in a wind. In the case of the HLH, this even includes precise hovering over a translating ship. This task requires a form of "ground" speed sensor to provide the pilot with an accurate position reference, or to provide automatic coupling. A simple electronic, fluidic, or optical device that can provide this information would have great benefits.

Auxiliary Controls. As the size of helicopters is increased, or as the demands for speed and manuverability are increased, the concept of new or additional force and moment producing devices arises. Usually this is in the context of performance (speed and payload). However, there are possible advantages to be gained for control. The ability of a very large helicopter to perform precision slung load placement in hover may be considerably enhanced by incorporating an auxiliary thrust vectoring capability. Similarly, an advanced attack or scout helicopter may be able to follow terrain more intimately if thrust vectoring could be used to reduce rotor and fuselage tilt angles when maneuvering. More exploratory studies should be funded to encourage innovation by contractors.

Control Elements Summary. The development of a complete flight control system tends to be expensive. The final product is as much a function of the ingenuity of the designer who implemented the idea as it is of the idea itself. Much of the work is in solving the details of the particular application rather than the basic concept. Because of this, control system development must be very carefully directed; it must either be kept simple or directed at a known requirement for a well defined system. The research topics discussed under control elements may be summarized as follows:

- Analyze to determine specific component needs
- Develop specific components
- Apply criteria and develop components to improve current systems
- Develop complete prototype control systems in support of major aviation systems

STABILITY AND CONTROL

General. To describe the work needed in stability and control and handling qualities, it is first necessary to discuss how the results of such work are used.

The design of an aircraft involves four basic functions:

- *Design goals:* It must be possible to define the desirable characteristics that should be designed into the vehicle.
- *Synthesis techniques:* It must be possible to synthesize a configuration that will achieve the design goals.
- *Prediction capabilities:* It must be possible to predict the characteristics of the proposed configuration.
- *Design evaluation:* It must be possible to evaluate the predicted characteristics against the goals.

The actual design process is a continuing series of iterations, matching goals against capabilities. If stability and control are considered as encompassing the tools required to perform these iterative design loops, the block diagram, figure AE–7, can be used to

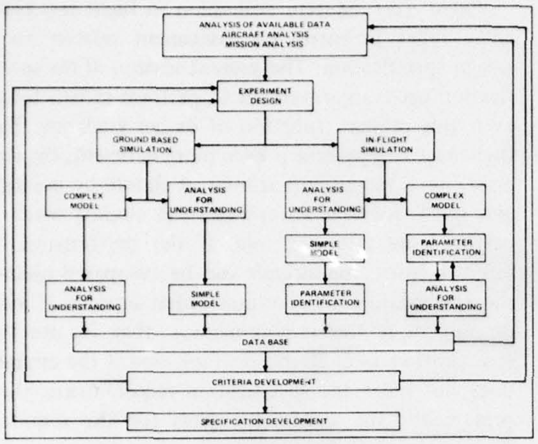


Figure AE–7. Design loop.

define the areas of stability and control that need research. Design goals, that is, criteria development, will be discussed in the subsection on handling qualities. Capabilities of analytical and wind-tunnel prediction of stability and control characteristics are covered in the aerodynamics and dynamics subsections. This leaves the capabilities related to ground and flight simulation, parameter identification, and flight test evaluation.

Mathematical Modeling. An essential part of stability and control work is the mathematical model. The form of model depends on the intended use, and can vary all the way from full global representation of all the known nonlinearities, boundaries, etc., appropriate to design assessment in the design loop (figure AE–7) to simple, decoupled linearized, small perturbation models, which are useful for analyzing and understanding stability and control aspects of flying qualities studies. One effort that is very much needed is to take the best available representations of current Army helicopters and simplify them by reducing them to the minimum number of parameters necessary for stability and control analysis. Specifically, determine the extent to which longitudinal and lateral-directional cross coupling, rotor/fuselage interference, and rotor dynamics have to be included, and how this should be done (e.g., for the rotor, is a first-order representation sufficient or is a second- or higher-order representation required?). No doubt a different model will be required for different helicopters (e.g., single, multi, and teetering or hingeless rotor, etc.), but these baseline characteristics must be defined to guide future generalized handling qualities research.

Wind Shear and Turbulence. The way turbulence and its intensity are modeled has a very strong effect on flying qualities simulations. Atmospheric turbulence at a fixed point varies with time, and at a particular time it varies from point to point, that is, it is time variant and space variant. For conventional aircraft, the speed is such that the time variations can be assumed negligible compared with the spatial variations. This assumption simplifies modeling, and is the basis for the most widely used models (e.g., that associated with MIL–F–8785B). However, this model is of questionable validity at low speeds and low altitudes, which are the conditions of primary importance for V/STOL aircraft and helicopters. Improvements are required in basic turbulence modeling, and in representing additional phenomena such as wind shear and discrete gusts produced by ground obstructions.

Ground Simulators. For conventional aircraft, the capabilities of ground simulators are generally strong. Unfortunately, the Army's use of helicopters as intimate ground contact machines imposes severe requirements, especially on the simulation of the out-the-window scene. In conventional aircraft, speed restricts turn rates so that attention is directed forward most of the time. In such circumstances, the field of view provided by a typical TV display (50° by 35°) may be adequate, though this is truer in the civil environment than the military, in which air combat or air-to-ground maneuvers require greater field of view. In helicopters and V/STOL aircraft, the slower speeds allow greater turn rates, and in the limiting case, hover, the aircraft can go sideways or straight up and down. The field of view required to perform such manuevers, especially in restricted areas such as a clearing in the woods, or nap-of-the-earth flying, is obviously very much greater. Flight at night introduces other considerations; although a helicopter can be hovered in daylight with a restricted field of view, the less distinct details that characterize darkness, for example, require the pilot to search an increasing field of view for the cues he needs to control the aircraft. Hence, simulation of night VMC puts considerable emphasis on providing peripheral cues.

Not only is there a need for a wide field of view, but detail and resolution are also particularly important for Army helicopter tasks such as low-level (NOE) operations. The intimacy between the helicopter and the ground on Army missions necessitates highly detailed terrain scenes; if one is to investigate

flight below treetop level, the trees must be represented in the visual scene. With high detail comes a corollary requirement to provide high resolution so that the detail can be seen. The requirement for a wide field of view exascerbates the resolution problem since the available picture density has to be spread out over a larger field.

Currently, there are no research simulator facilities available that are adequate for studying Army missions. There is a strong need for such tools, both for support of the DARCOM program managers and the helicopter contractors during system development, and as a tool for an R&D program directed at the topics discussed in this technology section.

Parameter Identification. Unless the capability exists to determine stability and control parameters from flight test, the feedback of information from flight test simulation or aircraft evaluation must be qualitative. In flight simulation, there cannot even be any confidence that the desired characteristics were actually simulated, unless they are identified. In the past decade, notable advances in parameter estimation techniques and their application to flight test measurements have been made. The need has existed for many years, but only recently have the highly automated data acquisition systems and advanced estimation techniques been available that can extract the information efficiently and accurately. Most flight test organizations now have experience with one or more parameter identification techniques to determine aircraft stability and control derivatives for conventional aircraft. Initial efforts in helicopter identification have been undertaken, but much more work is necessary before helicopter parameter identification becomes a widely accepted method of determining stability and control characteristics. Helicopters are more difficult to treat than fixed-wing aircraft because the highly vibrating environment produces significant sensor noise, and the non-negligible longitudinal to lateral-directional coupling, and the rotor dynamics, require a very high-order model. If nonsteady (transitioning) flight conditions are included as well, then helicopters share with other VTOL aircraft the extra problem of nonlinear or time-varying equations. A major effort should be made to improve helicopter identification capabilities. This can be accomplished by application of such techniques to current Army helicopters, thereby improving knowledge of our present aircraft and providing a much needed design data base. Parameter identification should also be made an essential ingredient of all flying qualities flight test programs.

Flight Test. System evaluation in flight test presently relies primarily on assessment relative to a design specification. The present version of the specification needs improvement to perform satisfactorily even this primary function of design guidance. The flight test comparison is even more deficient. In principle, once the aircraft is built, it should be possible and most desirable to evaluate the aircraft while it performs its intended role. If the performance is unsatisfactory, the aircraft can be compared against the specification to determine what aspects, if any, do not meet the requirements – that is, use the specification as a diagnostic tool, and if the aircraft does not meet the specification requirements, then presumably the contractor pays for the required fixes. Routine flight evaluation against design specifications is universal for fixed-wing as well as rotary-wing aircraft Some efforts must be made to develop more appropriate evaluation methods.

Stability and Control Summary. The various topics discussed under the category of stability and control may be summarized as follows:

- Develop ground simulation capabilities
- Improve low level visual displays for ground simulators
- Develop turbulence models
- Perform analysis of current Army aircraft characteristics
- Develop better mathematical models of Army aircraft
- Develop in-flight simulator capabilities
- Develop and apply parameter identification techniques
- Improve flight test evaluation capabilities

HANDLING QUALITIES

General. Handling qualities describe the flying characteristics that determine the pilot's ability to perform a certain task and the level of workload involved. Since it is an overall assessment, handling qualities must bring together the following specialities involved in aircraft design:

- Aerodynamics
- Dynamics

- Stability and control, controllability, maneuverability
- Displays for guidance and control information
- Mission requirements
- Human factors

This integrated approach cannot be overemphasized. There is no use in performing display studies if the vehicle stability and control characteristics are ignored, nor is there any use in studying stability and control characteristics unless the mission requirements and available displays are considered.

Criteria Development. A principal objective of most handling qualities research work is criteria development. Hence, before looking at specific topics needing investigation, it is worthwhile to consider the criteria development process. The block diagram in figure AE–8 shows the general approach. Starting

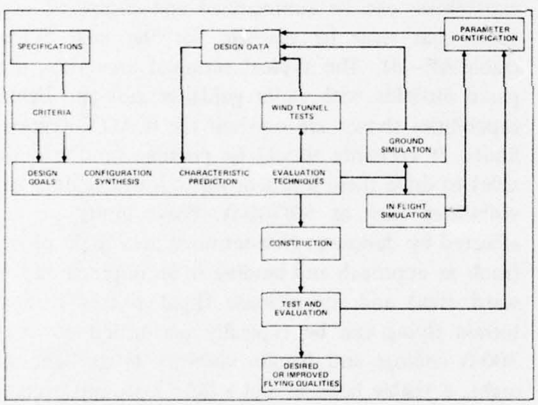


Figure AE–8. Generation of data for handling qualities criteria.

with an analysis of what is presently known about the area of interest, one can pick out the parameters of interest and the appropriate ranges for variation. As was discussed previously under stability and control, the models used may be simple or complex; both have their places in ground simulations and flight simulations. Suitable analysis may allow considerable simplification to be made to the model before performing the experiment. This will allow the results to be more readily associated with the parameters changed. Conversely, if a complex model is used, some form of analysis will be required to make the data useful for understanding the results before or during the attempt to develop criteria. Flight simulations must involve parameter identification to aid in setting up configurations and verifying what was actually simulated. Finally, the data must be analyzed, along with what was previously available, to determine if any general statements can be made for design goals or criteria. The extra step of formulating specifications must take a set of criteria and associate them with a concept of reliability so that benchmarks of minimum handling qualities can be entered into contractual documents.

Projects such as TAGS, the AH-56 in automatic terrain-following mode, or the Vertol 347 (HLH demonstrator) performing precision load placement in hover, illustrate that helicopters can be made to do almost anything desired of them; they can be made very easy to fly, or to fly themselves, if we are prepared to pay the price. Unfortunately, we can seldom afford to pay the price for the ultimate, most easily flown system. What we must do is define the minimum systems. We must define the stability and control characteristics (basic and augmented) that, when combined with appropriate displays or visual aids, allow adequate mission performance with tolerable pilot workload and cost-effective training (initial and proficiency).

A few very demanding tasks may take all the capability that the state of the art can muster. Some tasks may be performed with several equally good combinations of SAS/displays. For some aircraft it may be cheaper to install better than the minimum SAS/displays to minimize pilot workload and training requirements. These are decisions that can be made for a specific procurement; general research studies should emphasize defining minimums.

Having defined a research philosophy, the next task is to define the specific topics needing study. This must be approached through an analysis of Army mission requirements and a knowledge of present deficiencies.

Mission Analysis. Aircraft are designed to perform a role, for example, the AAH has the attack role, UTTAS has the utility transport role. The role involves many types of missions and each of these missions can be broken down into flight phases, for example, the AAH anti-tank defense mission may consist of the flight phases listed in table AE–C. The next detail is to associate an environment within which a particular flight phase must be performed. Day, night, visibility, and ceiling are the primary conditions, but wind and turbulence must be added

TABLE AE–C
TYPICAL FLIGHT PHASES FOR ANTITANK MISSIONS

SYMBOL	FLIGHT PHASE	FLIGHT PHASE GROUP*	SYMBOL	FLIGHT PHASE	FLIGHT PHASE GROUP*
VT	Vertical Takeoff	TA/NTA	TF	Terrain Flying	LA
VL	Vertical Landing	TA/NTA	LO	Loiter	LA/NTA
CL	Climb	UA	BO	Bob-Up Fire Track	LA/NTA
CR	Cruise	UA	EC	Evasion/Countermeasures	LA/NTA
D	Descent	LA			

*Flight phases have been grouped as follows:

TA	Terminal Area
LA	Low Altitude
UA	Up and Away
NTA	Non-Terminal Area

for flying qualities considerations. The general cases for consideration are: weather – clear, rain, snow, icing; and terrain – wooded, field, hilly, flat, snow covered, and sand. It must be noted here that although the capabilities desired are usually not well defined, they should be. It is inefficient to perform flying qualities research work to determine the minimum stability and control or display requirements necessary for a given mission, if the mission environment is ill-defined. One can contrast the situation for flying qualities with that for performance. In performance, it is categorically spelled out that the aircraft will have a maximum speed of at least *x* knots and will hover with *y* payload at altitude *h* and temperature *t*. Analogous objectives must be defined for the flying qualities environment.

Without going into detail as to which class of aircraft needs what minimum, some typical current capabilities can be summarized and compared with goals that may be realistic for the near future (table AE–D). The typical terminal area (i.e., prepared airfields with radio guidance aids and lights) capabilities shown are one-half the ICAO Category I limits. It certainly should be possible (and is desirable) to drive these limits down to lower ceilings and visibilities such as 50/700-ft. These limits are not affected by darkness. Non-terminal area flight phases (such as approach and landing in an unprepared forward area) and low-altitude flight phases such as terrain flying can be typically performed down to 300-ft ceilings and ½-mile visibility in daylight. At night, a visible horizon and a light level approaching

TABLE AE–D
TYPICAL AND DESIRED MISSION ENVIRONMENT CAPABILITIES

FLIGHT PHASE GROUPS		TERMINAL AREA		NON-TERMINAL AREA		LOW-ALTITUDE	
	CAPABILITY	TYPICAL	DESIRED	TYPICAL	DESIRED	TYPICAL	DESIRED
DAY	Ceiling - ft	100	50	300	50	300 AGL	50
	Visibility - ft	1200	700	1/2 mile	700	1/2 mile	700
	Wind ∿ knot	20 ± 15	35 ± 20	18 ± 10	35 ± 20	18 ± 20	35 ± 20
NIGHT	Ceiling - ft	100	50	500	50	500 AGL	50
	Visibility - ft	1200	700	1 mile	700	1 mile	700
	Light Level	0	0	Visible Horizon (VMC)	0	Visible Horizon (VMC)	0
	Wind ∿ knot	20 ±15	35 ± 20	18 ± 10	35 ± 10	18 ± 10	35 ± 20

that of a quarter moon is required. Under tactical situations, it is clearly desirable to drive these minimums down to some lower visual contact minimum such as 50/700 ft. Wind and turbulence can be a severe limitation in any of the flight phase groups and are particularly important in the non-terminal area and low-altitude flight phases since they manifest themselves through turbulence response and out-of-wind hover capability. Wind speed data was prepared by the USAF Environmental Technical Applications Center as background for revisions to specification MIL–F–8785B, "Flying Qualities of Piloted Airplanes." The data was taken from measurements at 266 airfields in the contiguous USA. Local terrain was generally flat, with 1 mile or more unobstructed flow upwind of the anemometer. Table AE–E summarizes these data and shows that a helicopter capable of flying in 34 knot wind would be limited less than 0.5 percent of the time (44 hr/year) in all but a few areas of the mountain and plain states. Even in these high wind areas, 34 knots would be exceeded less than 1 percent of the time (88 hr/year). Although Army operations will involve flight near obstructions and on mountain sides, where locally greater winds may be encountered, the 35 knot operating speed seems a reasonable near-term goal, and would approximately cut in half the current limits in operations.

In discussing areas to be emphasized, reference can be made to table AE–F, which lists some critical flight phases and the pertinent aircraft classes. DARCOM has defined night operations as a major thrust for RDT&E, particularly at low level. This thrust is designated LLNO for Low Level Night Operations. Under the umbrella LLNO there are two critical aircraft roles, scout and attack (ASH and AAH). Consider either one, for example, the AAH. The LLNO mission breakdown in table AE–F can be used as an example.

The Combat Developments and Experimentation Command, USACDEC, recently defined the potential capabilities of current systems (AH-1G and OH-58) to operate at low altitude at night, with absolute minimum aids. The capability to perform low-level flight (TF) is roughly as shown on figure AE–9. It was found that for flight phase TF, the primary obstacle was visibility. Since CDEC had no means of changing the aircraft stability and control characteristics, the effect of control and maneuverability was indeterminate. Experiments must be performed to determine how the stability and control characteristics influence the task performance and pilot training proficiency requirements. Flying qualities deficiencies were noted in flight phases LO, BO, and EC. These flight phases also need investigation. An overall conclusion was that though attack helicopter teams can operate at nap-of-the-earth altitudes under clear night conditions, they cannot routinely perform those interrelated acquisition tasks necessary to engage targets without a night acquisition system. Thus, an investigation of flying qualities in flight phase BO must include avionics equipment and specialists.

Clearly, it is desirable to keep the capability of performing the individual flight phases matched. As mentioned above, the ability to fly TF on a clear night exceeds the ability to acquire the target, BO. However, if aids are provided for target acquisition, capabilities will extend into dark night conditions, and possibly into deteriorating weather. In this case,

TABLE AE–E
WIND SPEED DATA

WIND SPEED (kt)	PROBABILITY OF ENCOUNTERING GREATER WIND %	AREA OF HIGH WIND
22	1.0	• Almost all of USA
28	1.0	• Parts of Rocky Mountains and Western Plain states
34	0.2	• Most of Rocky Mountains and Plain states
	0.5	• Small areas of Rocky Mountains and Plain states
	1.0	• No areas

TABLE AE–F
FLIGHT PHASES AIRCRAFT GROUPING

GROUP	FLIGHT PHASES	COMMENT	AIRCRAFT*
LOW ALTITUDE	NOE Contour Low Level	Terrain Flying	S/A S/A/U
	Bob Up	Include Acquisition Fire & Track	S/A
	Evasion		S/A/U/H
	Non-Terminal Approach to Hover Possibly Land	Zero or Minimum Ground Aids	S/A/U/H
INSTRUMENT METEOROLOGICAL CONDITIONS (IMC)	*Terminal Area Approach and Land:*		
	To Cat II	100 ft/1/4 mi	S/A/U/H
	Below Cat II	<100 ft and/or 1/4 mi	S/A/U/H
	Tailored Profiles	*e.g., Steep/Curved*	
	Elementary Enroute IMC	Prevent Disorientation	S/A/U/H
SLUNG LOAD	Precision Hover	May Be Performed While Terrain Flying	H/U
	Stability at Speed		H/U
MULTIPLE AIRCRAFT	Formation Flight		S/A/U/H
	Air-to-Air Combat		A
*AIRCRAFT	S- SCOUT	OH-6, OH-58, ASH	
	A- ATTACH	AH-1G, AH-64	
	U- UTILITY	UH-1, UH-60	
	H- HEAVY LIFT	CH-47, CH-54, MLH	

it will be the TF flight phase that trails. Hence, a long-term program objective must be to improve LLNO mission capability by continued focus on the weakest link in the flight phase chain. Ground simulations, flight simulations, and work with instrumented attack and scout aircraft (e.g., AH-1G and OH-58) are all appropriate for these efforts.

The more general category of IMC is not explicitly a major thrust, but is, nonetheless, an important area needing long-term research to generate systematic criteria. There are of course several degrees of IMC and many flight phases which can be conducted under IMC. Perhaps the most elementary IMC capability is to be able to survive an unexpected encounter with IMC conditions (such as haze, darkness, dust, night blindness from flares or searchlights, etc.) when performing up and away (UA) flying. This capability is by no means universal in current Army helicopters and considerable effort should be made to ensure that the next generation is improved in this regard. There is much room for improvement to bring helicopter flying qualities at least up to those for fixed wing. Figure AE–10 compares the percentage of accidents due to disorientation error in Army rotary-wing aircraft with those in Army fixed-wing aircraft. In 1969, this consisted of 65 rotary-wing accidents; 20 were fatal, and the cost to the Army of aircraft alone was $11.7 million. Research is needed to determine means of preventing such accidents, but there will be a trade-off between stability and control and display characteristics and between pilot training and proficiency. Figure AE–11 shows how 8000 Army pilots answered the question: How many hours of instrument flight time would you need with an instructor in order for you to fly in IMC safely? Obviously rotary-wing aircraft are more difficult to fly, and a program to improve the flying qualities, at least to

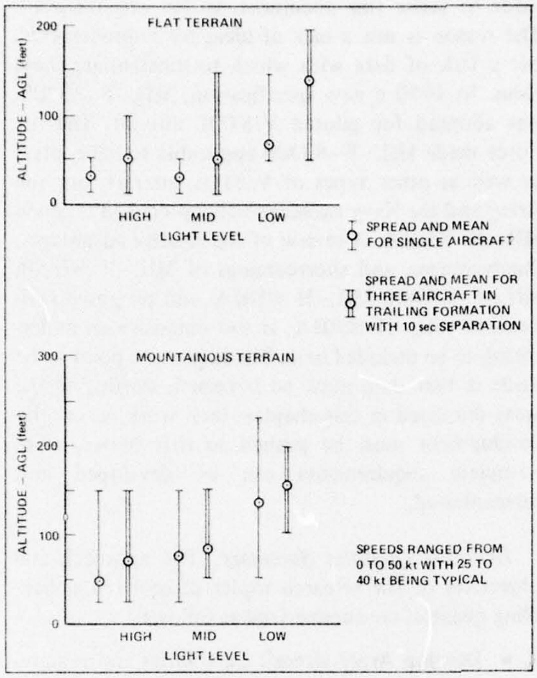


Figure AE–9. Unaided LLNO capabilities.

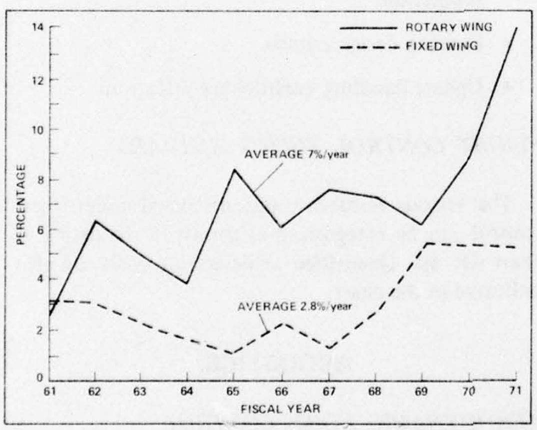


Figure AE–10. Percentage of accidents in which disorientation was a cause factor.

fixed-wing standards, should reduce accidents and have the additional benefit of reducing training and proficiency costs. Thus, a broad program of improving rotary-wing flying qualities in IMC should be a major objective. This will start with the elementary ability to avoid disorientation if IMC conditions are suddenly encountered, and move into increasingly severe terminal area conditions as seem appropriate from mission studies.

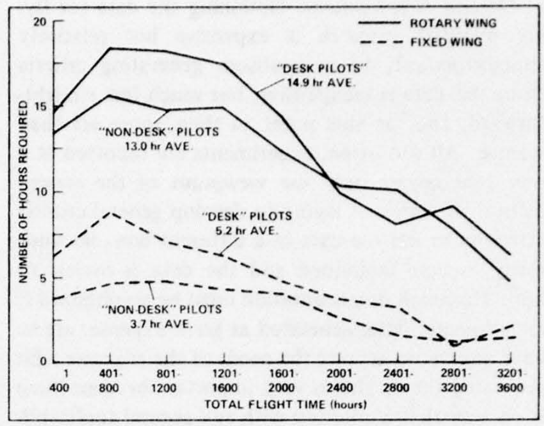


Figure AE–11. Estimated time with instructor in order to become IMC first pilot proficient.

The type of approaches to be considered should start with simple approach profiles, that is, straight-in approaches, or skewed approaches as would be appropriate for a collocated glide-slope and localizer transmitter, with descent angles in the range of 6° to 20°. These should be investigated to Category II conditions. The speed profile should be determined to give the simplest control and display requirements. The studies should then be extended to investigate requirements for simple approaches to lower minimums such as the Category IIIa, b, and c, or Category IIIa and b with decision height modified to 50 ft. In the Category III cases, it will probably be necessary to decelerate as the descent proceeds. Again, the simplest procedures should be determined. Consideration should also be given to whether the task is for one or two pilots, and if both must be fully qualified. It must be realized that for these studies, the important aspect of displays is what information the pilot needs and how it should be displayed. Whether this information is obtained from the ground, or is from self-contained equipment, is important only to the extent that it is practical. The work does, however, provide an efficient opportunity to exercise specific navigation and guidance equipment. Having determined the simplest guidance and control requirements to make approaches in poor terminal area conditions, it would then be appropriate to examine the capability of performing specially tailored approaches. Such profiles may include very steep approaches, or approaches that minimize fuel used, exposure to the area surrounding the landing site, or time sequenced approaches. Again, to obtain maximum benefit from the available research resources, mission analysis must be a prelude to guide the choice of approaches to be investigated.

Criteria Development. Obtaining the data for flying qualities research is expensive but relatively straightforward. In comparison, generating criteria from the data is inexpensive, but much less straightforward, and, at this point in time, more art than science. All too often, experiments are reported in a way that covers only the viewpoint of the experimenter. If someone trying to develop general criteria attempts to use the data in a different way, he finds many aspects undefined and the data is useless to him. Thorough documentation must be emphasized if experimental data, generated at great expense, are to have any value beyond the needs of the engineer who generated them. This is very important because there is no way that a criterion with any general applicability can be developed from the results of one program.

Many of the stability and control characteristics of an aircraft can be defined by the response to a single control or an external disturbance. This will be termed open loop response even through stability augmentation loops may be closed. These open-loop responses are relatively easy for a designer to evaluate during design, and have therefore been widely used for criteria and specifications. However, there are many flight situations where it is more important to look at the response to a disturbance or control while the pilot is controlling the aircraft with the same or another control. This will be called closed-loop response. Control of speed and descent rate during landing approach is usually a two-control, closed-loop situation; for example, longitudinal cyclic or pitch control to control attitude, and then mixtures of attitude change and collective inputs to control speed and descent rate. This is a complex situation to analyze because there are many parameters that influence the flying qualities. One tool that may be useful in analyzing and obtaining an understanding of such closed-loop, multiple input/output situations is the use of an analytical pilot model. However, what is being advocated is the application of available pilot models, not the development of new, more complicated models. Available models are already more complex than required and have to be simplified for useful application. Work in the near future should be toward more systematic application of pilot models where they appear to be useful.

Specifications. Since a primary use of stability and control criteria is to generate and improve flying qualities specifications, a few words are warranted on the current specification status. The helicopter flying qualities specification MIL–H–8501A is a 1962 revision of a 1952 document. Several efforts have been made to revise this document, so far without avail. The reason is not a lack of ideas for improvements, but a lack of data with which to substantiate these ideas. In 1970 a new specification, MIL–F–83300, was adopted for piloted V/STOL aircraft. The Air Force made MIL–F–83300 applicable to helicopters as well as other types of V/STOL aircraft, but the Army and the Navy excluded helicopters and retained MIL–H–8501A. A review of the relative advantages, disadvantages, and shortcomings of MIL–F–8785B, MIL–F–83300, MIL–H–8501A, and proposed revisions to MIL–H–8501A, is too extensive an undertaking to be included here. The important point to be made is that data must be obtained, starting in the areas discussed in this chapter; then work on criteria development must be pushed so that better, more complete requirements can be developed and substantiated.

Handling Qualities Summary. The approach and objectives of the research topics categorized as handling qualities are summarized as follows:

- Develop Army aircraft capabilities and requirements through mission analysis
- Develop data base through ground and in-flight simulation
- Develop design criteria
- Update handling qualities specifications

FLIGHT CONTROL TOPICS SUMMARY

The various research topics discussed under flight control can be categorized as shown in the listing in chart AE–III. Quantified achievement goals are also indicated in the chart.

ACOUSTICS

AERODYNAMIC NOISE CONTROL

General. Acoustic waves originating on the advancing blade of typical rotary-wing configurations produce a distinguishing acoustic signature described as blade slap. In addition, strong near-field interactions can occur between both mixing pockets and tip vortices within the rotor wake and the rotor blades that cause them, thus producing a combination of impulsive harmonic noise. Superimposed on these events is a significant measure of broadband noise due in part to inflow turbulence and localized blade stall. Mechanical sources of noise, which stem from the

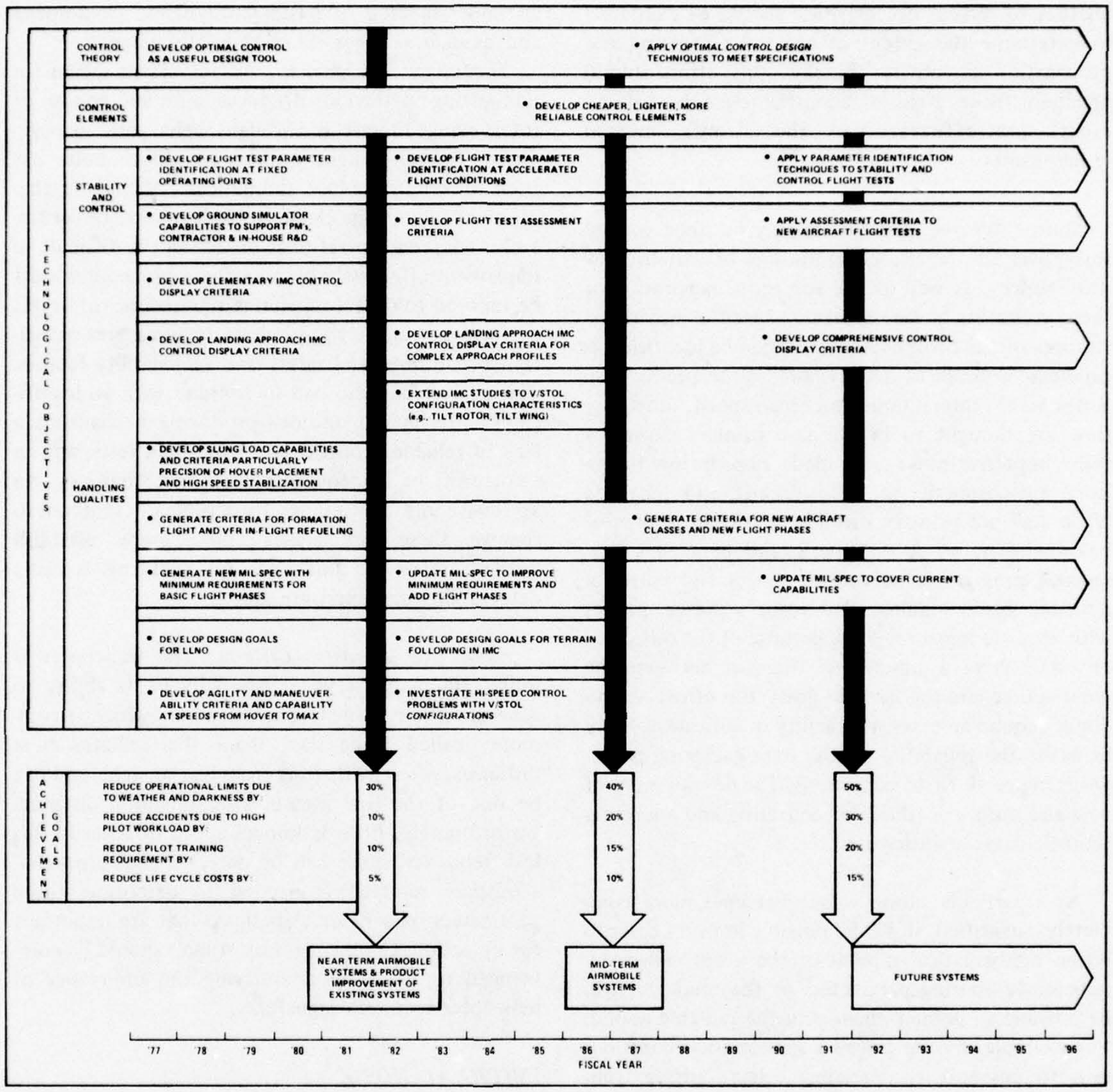


Chart AE–III. Summary of flight controls objectives and achievement goals.

engine and transmission, add to the acoustic problem, and are discussed in a separate section of this plan. Regardless of the source of noise, be it aerodynamic or mechanical, the advent of larger rotorcraft flying at even higher subsonic forward speeds will be plagued with further increases in external and internal noise levels to the extent that detectability, annoyance, and crew health could seriously limit mission effectiveness during tactical and training operations.

Noise-Performance System Studies. It is generally known that decreasing rotor tip speed is often an effective way of decreasing the external noise levels of rotary-wing aircraft. Unfortunately, decreasing noise levels through tip speed reductions is expensive in terms of vehicle performance. Whether such tip speed reductions or other methods of reducing noise are important enough to warrant performance sacrifices for a particular helicopter configuration are questions best answered through systematic parametric studies. Such studies should focus on all aspects of noise control; controlling noise at the source, propagation, and detection. Competing methods of controlling noise at the source should be examined to determine the effectiveness and cost in tactical situations. Typical rotorcraft maneuvers, in

relation to terrain irregularities, should be examined to determine the extent of spectral reordering and propagation directivity. Finally, this effort should highlight those areas of acoustic research that are most cost-effective to the Army's mission requirements.

Source Control. While there may be some controversy over the precise contributions of various flow disturbances, as well as the subjective perception of their collective noise signature, specific discernible features of the rotor environment can be identified as candidate sources of aerodynamic noise production. Rotor-wake interaction and high-speed, unsteady flow are thought to be the two primary causes of rotor impulsive noise – or blade slap. Inflow turbulence (atmospheric or self-induced) and localized blade stall are primary candidates for the source of broadband noise. A systematic and detailed experimental program is needed to collect and correlate dynamic blade loadings and rotor wake properties with acoustic measurements. Because of the difficulty of establishing a unique relationship between the noise source and the far-field noise, this effort will no doubt require an extensive facility qualification study to assess the reliability of the data gathering procedures under all flight conditions. The development of new and unique methods of collecting and analyzing acoustic data are anticipated.

As a particular noise source becomes more completely quantified, it will be possible in many cases to refine mathematical models of the event. Then, by judiciously altering parameters of the model, it will be possible to predict changes in the radiated sound. For example, having traced a sizable noise contribution to unsteady compressible effects arising from interactions of the rotor blade and the tip vortex, it seems natural to question the potential of a reorientation of the individual blades within the rotor system. Suggested modifications include blade sets with different diameters, uneven angles between blades (either permanently fixed or variable in flight), and unequal elevations of the tip path planes of two sets of blades. Other than merely trying to avoid strong vortex interactions, it is conceivable that the strength and trajectory of each tip vortex can be favorably altered through new blade tip geometries or airflow injection. Rational and systematic assessments of these approaches, and the performance penalties they might entail, require the development of advanced aerodynamic and acoustic models. These theoretical and experimental techniques are interdependent with an understanding of basic aerodynamic phenomena and, as such, rely heavily on those disciplines.

Trajectory Management. An important means for minimizing detection distances and annoyance of rotary-wing aircraft is through flight path management. Tailoring flight profiles to reduce noise has been shown to reduce dramatically the blade slap problem on certain classes of helicopters. Unfortunately, adapting operational procedures is difficult to implement effectively because these procedures must be tailored to reflect mission requirements, rotorcraft performance and stability characteristics, area navigation constraints, and safety and survivability factors. The analyst has also had to contend with an insufficient understanding of noise-producing mechanisms, a lack of reliable acoustic data from field tests, and an assortment of inadequate prediction techniques. An aggressive and continuing effort is clearly required to remove these deficiencies and thereby establish needed trajectory guidelines for reducing acoustic detectability and exposure time.

Subjective Acoustic Criteria. The helicopter is unique in many ways – especially in its ability to generate intense low-frequency noise, which is commonly called blade slap. Blade slap radiates great distances, often diffracting from line of sight, and can be one of the first measures of detection distance. Unfortunately, little is known about how easily this low-frequency noise can be detected. Basic psychoacoustical research is needed to determine those parameters of a blade slap signal that are important for detection. Complementary studies should be commenced to focus on quantifying the annoyance of helicopter acoustical signatures.

INTERNAL NOISE

High noise levels in the cockpit of modern helicopters is common. Large power generating and transmission devices are, because of unavoidable design factors, located in proximity to crew stations and usually dominate internal noise levels. Although it is possible to place acoustic blankets over these noise sources, current noise reduction materials decrease noise by the mass law and, as such, are quite heavy. Current Army practice is to do what can be done to reduce cockpit noise at reasonable cost and then design helmets to protect crew members from excessive noise. Although not the most ideal solution to the problem, it is one that minimizes performance sacrifices in helicopter design. Additional effort should be expended to lower internal noise levels

through better engine and transmission design and to develop isolation materials that reduce noise and are relatively lightweight. These topics are addressed in a different section of this Plan.

ACOUSTICS TOPICS SUMMARY

The various research topics discussed under acoustics can be categorized as shown in the listing in chart AE–IV. Quantified achievement goals are also indicated in the chart.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The project Selection Process philosophy and system elements are presented in the Technology Introduction section of the Plan. This section applies that process to the aerodynamics discipline for the near-term time frame. The OPR is not an objective of the Plan, but is provided to show the procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the aerodynamics discipline can be established from the near-term quantified achievement goals listed in charts AE–I through AE–IV. The near-term aerodynamics objectives are of two types: first, those which will result in direct technology improvements and second, those which improve prediction capability and produce indirect technology and cost improvements. The aerodynamics objectives are as follows:

- Achieve ±10 percent accuracy in the prediction of overall dB level of aerodynamically generated noise and reduce this noise by 15 percent.
- Achieve 20 percent improvement in predictability of stability and control characteristics.
- Determine handling qualities criteria for LLNO/NOE operation and increase agility by 10 percent.
- Reduce accidents due to pilot workload by 10 percent.
- Reduce pilot training requirements by 10 percent.
- Improve aeromechanical stability prediction techniques to ±10 percent of measured values.
- Reduce cockpit vibration levels by 50 percent with minimum weight penalty.
- Achieve 20 percent reduction in vibratory blade stresses and control system loads through stall modification.
- Achieve ±10 percent prediction error in key performance parameters.
- Achieve 10 percent improvement in performance through use of advanced airfoil sections and reduced airframe and hub drag.

PROGRAM PRIORITIES

General. Table AE–G presents, in a prioritized listing, the aerodynamics technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The aerodynamics technology subdisciplines are represented by the major topical areas as presented in table AE–B.

Vehicle Subsystems. Vehicle subsystems, as related to aerodynamics technology, are categorized as follows:

- Lift/propulsion elements – rotors, propellers, wings.
- Auxiliary control elements – tail rotors, control surfaces.
- Parasitic elements – fuselage, landing gear, external equipment.

These are the vehicle subsystems that produce significant aerodynamic forces and moments and thus have the largest effect on flight characteristics.

System Effectiveness. In the area of systems effectiveness, acoustics and control capability have a direct effect on survivability of the aircraft system. The vibration characteristics have a significant effect on

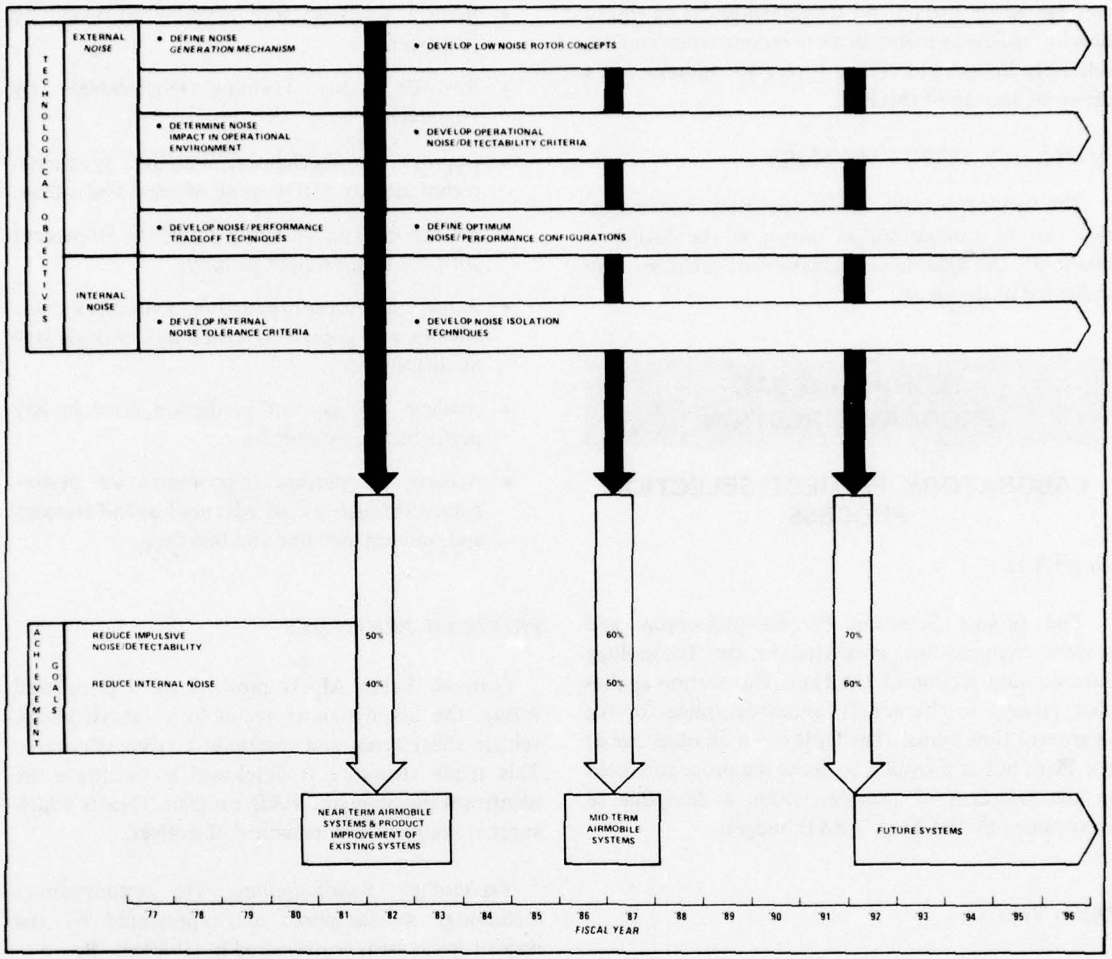


Chart AE–IV. Summary of acoustic objectives and achievement goals.

TABLE AE–G
PRIORITIZED AERODYNAMICS OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Fluid mechanics	I	• Main rotor	I	• Survivability	I
• Dynamics	II	• Tail rotor	II	• R&M cost	II
• Acoustics	III	• Flight controls	III	• System cost	III
• Flight control	IV	• Fuselage	IV	• System volume	IV
				• Fuel efficiency	V

R&M costs of the system, while performance characteristics and fuel efficiency combine to define the aircraft size and cost to perform a given mission. Overall, aerodynamics technology is a major determinant in aircraft system life-cycle costs.

Priorities. With reference to table AE–G, the aerodynamic subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the aerodynamics R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 aerodynamics technology development program.

Assessment of the priority listing in table AE–G and the near-term objectives indicates that the first priority major thrust in aerodynamics technology is consistent with the first and second objectives listed above and is aimed at improving the survivability of aircraft systems to make them more effective. If an aircraft is not survivable, all other aspects of life-cycle cost are relatively insignificant. In addition to surviving in a combat environment, an aircraft system must be effective, and flight controls, dynamics and performance characteristics are all tailored to produce a cost effective system. Each one of these elements is necessary to developing systems with acceptable life-cycle costs, and the Laboratory thrusts are developed to provide aerodynamics technology that will result in the highest payoff in system cost in the shortest elapsed time.

LABORATORY PROJECTS FOR FY78 IN AERODYNAMICS

INTRODUCTION

The aerodynamics technological development effort is directed toward research and exploratory development to increase knowledge in the physical and behavioral sciences. This effort is conducted primarily by the Aeromechanics Laboratory and the Structures Laboratory collocated with NASA Ames and Langley for the 6.1, 6.2, and some 6.3 efforts and with the addition of the Applied Technology Laboratory for 6.2 and 6.3 efforts.

Programs at the Aeromechanics Laboratory are primarily in areas of rotor aeromechanics, rotor dynamics, stability and control, handling qualities and aerodynamically generated noise, and are influenced by the availability of such facilities as the Army 7- by 10-Foot Low-Speed Wind Tunnel, NASA's 40- by 80-Foot Full-Scale Wind Tunnel, and NASA's Ground-Based Simulators, and a new major emphasis on flight research.

Programs at the Structures Laboratory include work on airfoil research and development, unsteady aerodynamic phenomena, rotor wake and tip-vortex characteristics, aeroelastic stability and transient response, vibration reduction, anti-torque concepts, stability derivative prediction, rotor-fuselage interactions, prediction of airfoil operating requirements, rotor tip shapes, control and guidance avionics, handling qualities, operations, acoustics, configuration performance, hover performance, and IR suppression. Facilities used to implement this research include the Generalized Rotor Model System (GRMS), V/STOL wind tunnel, laser velocimeter, Transonic Dynamics Tunnel, Aeroelastic Rotor Experimental System, rotor whirl tower, 6- by 28-in. wind tunnel, 6- by 19-in. wind tunnel, 7- by 10-ft wind tunnel, VALT CH-47, and SH-3, UH-1H, AH-1G, OH-58, computer facilities, and ground-based and flight simulators.

Programs at the Applied Technology Laboratory are in the 6.2 and 6.3 categories and cover such areas as helicopter aerodynamics, aeroelastics, dynamics, stability and control, development and verification of analytical programs, comprehensive aeromechanics mathematical modeling, and the development and evaluation of advanced rotor and flight control concepts.

DESCRIPTION OF PROJECTS

Research in Aerodynamics. Project 1L161102AH45-TA I consists of basic and applied research conducted in participation with NASA to develop the aeronautical technologies of rotary-wing aircraft. These in-house, theoretical and experimental investigations are directed toward elimination of the technological voids that are assessed to be potential limiting factors in the development of future superior, reliable, and economical Army airmobile systems. The work performed under this project at the Aeromechanics Laboratory and Structures Laboratory is a coordinated and complementary aerodynamic research effort. The division of this aeronautical research between these two Laboratories is

primarily determined by the particular facilities and/or expertise uniquely available to each. This enables the Laboratory Management to bring all the capability in aeronautical research that is available to these two Laboratories to bear on the problems relevant to Army airmobile systems in the most effective manner.

Aerodynamics Technology. Project 1L262209AH76-TA I is an exploratory effort to develop and demonstrate the technologies, techniques, and design criteria necessary to provide adequate performance, acoustic signatures, stability, control and handling qualities for the Army's rotary wing missions, and to improve the capability to analyze and predict these characteristics in existing and future aircraft. This technology will increase the aircraft's availability and survivability as well as provide for improved operational effectiveness and mission capability of Army aviation systems. Research from this project will provide part of the analytical and design techniques necessary for establishing realistic design goals and making valid prediction and analyses of the performance, handling qualities, stability and control, and acoustic signature, thereby increasing the potential of achieving design-to-cost objectives within the Army. These research objectives are accomplished by the Applied Technology Structures and Aeromechanics Laboratories in participation with NASA. The programs involve analytical and experimental investigations utilizing ground based and in-flight simulators, wind tunnel, and flight test investigations.

Advanced Helicopter Development. The objective of Project 1L263211D157 is an advanced development effort for the development, verification, and demonstration of technology for those areas currently restricting the success of current Army airmobile systems or areas that have prevented the achievement of future Army aviation objectives. The project is formulated on the basis that advances in state-of-the-art technology can only be made if technology is validated in component or system demonstration in actual or simulated flight conditions.

This project consists of the following four major tasks areas:

- *Task 11 – Advanced Rotor Development.* Under this task advanced rotor systems are developed by the Aeromechanics Laboratories, with selected concepts jointly funded by NASA. The program is oriented toward a variety of systems, a substantial number of which will be developed through the use of the Rotor Systems Research Aircraft (see Section AT – Advanced Technology Demonstration). The Bearingless Main Rotor which will be demonstrated on the BO-105 helicopter is the current major effort.

- *Task 12 – Rotor and Control Improvements.* The objective of the flight control portion of this project is the development, verification, and application of improved flight control elements to provide improved mission capability and survivability, and/or improve reliability, maintainability and cost effectiveness. Scope includes the integration of control system elements and displays into the aircraft system performing the appropriate tasks. Efforts have centered on demonstration of fluidic SAS components, fan-in-fin yaw control, and TAGS/pilot cueing. A major thrust for the future will be to apply the results of 6.2 exploratory development to include the capabilities of performing low-altitude operations in poor visibility conditions (LLNO) with minimum dependence on expensive and complex equipment. To prepare for this, an in-flight simulator being developed by NASA has been converted into a joint program with the Aeromechanics Laboratory. This will provide the capability to investigate stability and control and display trade-offs while performing LLNO flight tasks. Development of control system hardware is a function of the Applied Technology Laboratory with primary emphasis on fly-by-wire development and demonstration.

- *Task 17 – Advancing Blade Concept.* Demonstration of the ABC in the helicopter mode has been completed. The Navy and NASA have joined the Army in support of demonstration of the compound, high-speed configuration of the ABC which will be flown to speeds approaching 30 knots. See Section AT for additional material on the ABC program.

- *Task 18 – Second Generation Comprehensive Helicopter Analysis System.* An interdisciplinary aeromechanics analysis system for rotorcraft is being developed to provide an integrated analysis capability for prediction of rotorcraft loads, performance, stability and

control, dynamics and acoustics. This analysis system will serve as a focal point for aeromechanics methods development and provide preliminary design, detail design, and development support for systems under development through the 1990 time frame. Multiple predesign studies are under way to define development options in more detail. A Government/ Industry Working Group has formulated requirements for the system and will assist in monitoring its development.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the aerodynamics R&D efforts as presented in the technical discussion are shown and discussed in the Resources Required section. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.1, 6.2, and 6.3 aerodynamics R&D efforts are shown in table AE–H. Included in the table is the ratio of the aerodynamics efforts to the total 6.1, 6.2, and 6.3 Laboratory R&D efforts.

TABLE AE–H
AERODYNAMIC TECHNOLOGY FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78	
6.1	1F161102AH45-TA I	2227	50%
6.2	1F262209AH76-TA I	1875	12%*
6.3	1F263211D157	4303	30%

*Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.

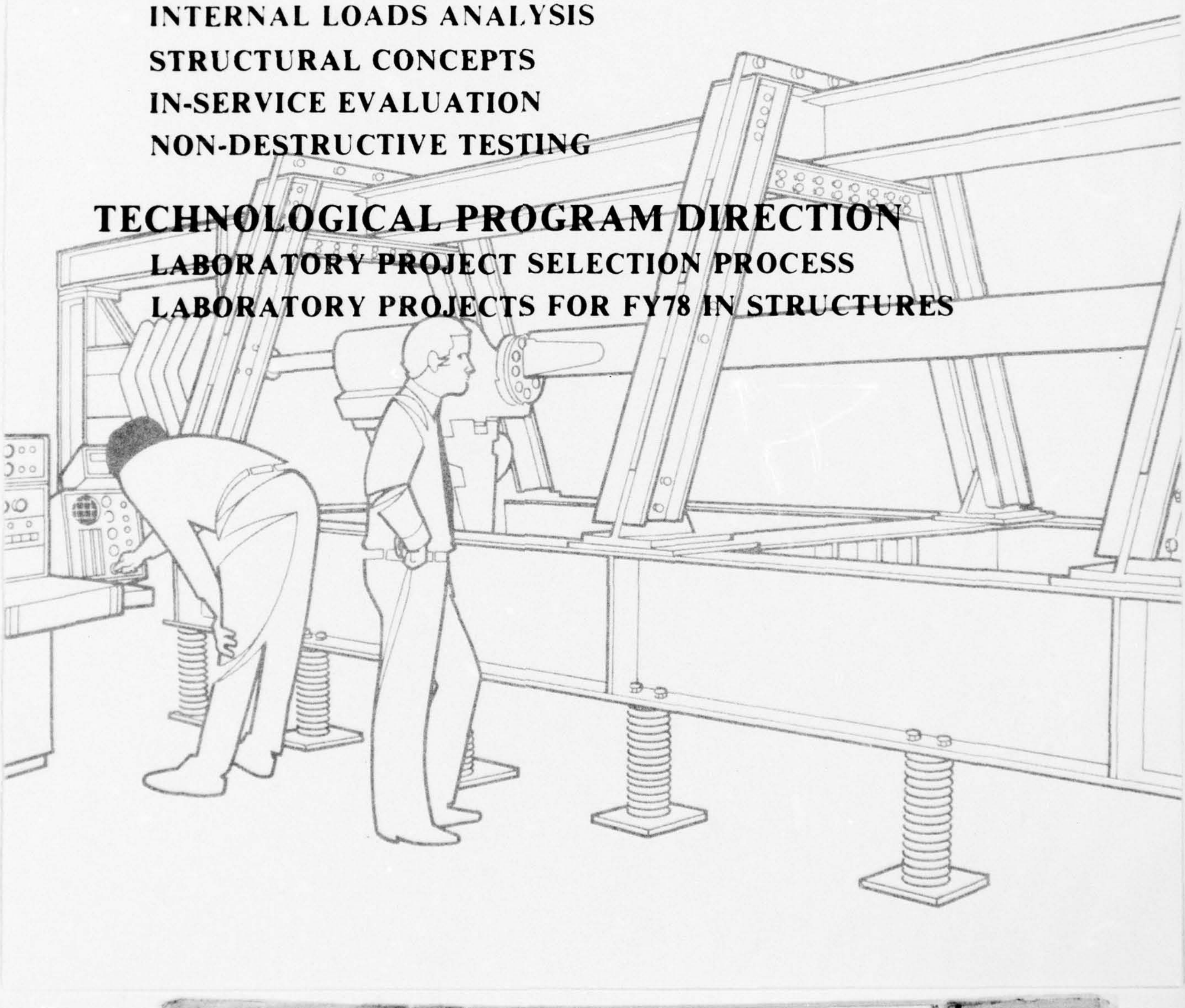
INTRODUCTION

TECHNOLOGICAL DISCUSSION

CRITERIA
WEIGHT PREDICTION
MATERIAL ENGINEERING
EXTERNAL LOADS ANALYSIS
INTERNAL LOADS ANALYSIS
STRUCTURAL CONCEPTS
IN-SERVICE EVALUATION
NON-DESTRUCTIVE TESTING

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS
LABORATORY PROJECTS FOR FY78 IN STRUCTURES



INTRODUCTION

The structures technology area offers one of the greatest payoffs from a well-planned and well-funded program: reduced structural weight, dynamic tailorability, reduced maintenance, increased reliability, improved survivability, and reduced costs can be applied to the next generation of Army aircraft. Potential future Army aircraft systems include a variety of aircraft varying in size from small scout vehicles to very heavy lift aircraft. In each case, the supporting research and technology in the structures area must be guided by past operational experience and present technological limitations. The extensive use of helicopters in Southeast Asia has drawn into focus structural deficiencies and lack of adequate structural design criteria for Army aircraft. The environment, operational procedures, load spectra, and mission profiles represent a use virtually foreign to the original design criteria or military specifications for their structural design. This lack has been reflected in tail rotor failures, tail boom failures, flight control component failures, limited-life dynamic components, fatigue cracking of the basic airframe, and other structural failures. The helicopter's record of fatigue failure accidents remains very poor when judged by fixed-wing standards. The mission requirements of future aircraft systems require an expanded operating envelope involving speed and maneuverability. These requirements must be met with an aircraft that is highly survivable, rugged, and reliable, and that requires a minimum of maintenance and inspection, at a reasonable cost. Improving structural efficiency through research will minimize unproductive weight in future aircraft, permit these requirements to be met, and reduce operating costs.

This research and development activity is, to a great extent, applicable to all of the Army's planned airmobile missions. In some instances specific R&D activities are required to resolve key problems peculiar to certain missions. Examples of the latter are:

- The second generation aerial weapons systems require an aircraft with exceptional survivability characteristics. Research and development activities include the development of armor materials that can defeat projectiles yet have minimum weight and perform effectively as primary structure. Analytical techniques, materials, and structural concepts need to be improved and developed to safely tolerate gross combat damage from high-energy projectiles in unarmored structure.
- The mobility and intelligence missions will require advanced rotor systems, which might include tilt rotors or tilt wings. New design concepts, structural criteria, weight methods, and loads prediction methods will be developed to ensure that these concepts become structurally effective systems.
- The mobility mission for oversize payloads requires a lifting capability in the range of 22.5 to 50 tons. Current estimates indicate that conventional propulsion systems might not be adequate for a conventional type VTOL vehicle. Materials and structural concepts can be developed to provide off-the-shelf technology for reaction-drive concepts.

The requirement for expanded flight envelopes, the extremely difficult loads environment, and the complexity of VTOL systems dictate the need for an extensive structures program. The development of better analytical tools must be coupled with a better understanding of loads, stresses, and design criteria for the total spectrum of vehicle concepts being considered. Experimental flight test programs involving aerodynamics and dynamic and structural instrumentation must be conducted to guide and substantiate the analytical techniques. These analytical tools must be verified through design, fabrication, and test of actual structural components that also demonstrate, in flight programs, the confidence required to put the structures technology on-the-shelf for developmental aircraft.

A balanced research and development program must be carried out in each of the subdisciplines to achieve the required technological goals to support the Army's projected aircraft system needs in the structures area. The subsystems include structural criteria, weight prediction methods, materials engineering, external loads, internal loads, fatigue and fracture mechanics methods, structural concepts, in service evaluation, and non-destructive testing. Each subdiscipline is interdependent on the others. As efforts progress from basic research through applied research and development, this interdependency of the subdisciplines makes quantitative improvement goals more sensitive to the pacing key parameter. There is also an interdiscipline dependency that will affect the attainment of future quantitative goals in the subdiscipline

areas (i.e., improvements in predicting external loads are dependent on improved understanding of the aerodynamics and dynamics).

TECHNOLOGICAL DISCUSSION

CRITERIA

Structural criteria are developed for each aircraft system from the expected use of the vehicle. They define the critical design requirement to be met in the design, satisfied in the fabrication, and substantiated during testing. The criteria, when met and substantiated, ensure the structural integrity of the operational fleet of aircraft. At the present time, structural criteria for Army aircraft are based on military specifications, specific mission requirements of the aircraft to be developed, and the Helicopter Engineering AMCP 706–201–203.

The recent advances in rotary wing aircraft performance and the greatly expanded combat role have made the existing military specifications for helicopters inadequate. This inadequacy in structural criteria, with the changing mission, has been shown in the fatigue-limited life of many components, the amount of maintenance required, and the less than desired survivability. In addition, design criteria do not exist for advanced systems, such as compound helicopters and tilt rotors that have capability beyond present experience.

The basic objective of research and development in this area is to establish requirements that will ensure an acceptable design life for the intended mission. The criteria must be complete to ensure that all critical parameters are considered during design to avoid costly design changes during aircraft development and test and retrofit after deployment. Most importantly, the criteria must be adequate to prevent catastrophic failures.

One measure of adequate structural criteria is the life of critical components. Ideally, the life of all components would be the same as the design life for the aircraft. At present, many components have limited lives requiring expensive removal and replacement. It is recognized, however, that in some cases life cycle cost analysis might justify selection of a component life less than the system life. For those parts that have a limited life, it is desirable that they be removed only when there is an indication of an obvious degradation, rather than at some pre-established number of hours, a number based on the most severe case in the inventory. The "on-condition" removal allows the components on an aircraft subjected to more moderate use to have an extended life. Figure ST–1 shows objectives for improvements in these two parameters of design life and on conditional replacement of limited-life parts.

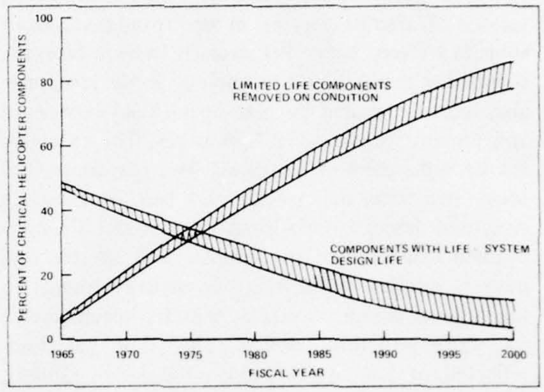


Figure ST–1. Structural criteria improvement goals.

There are many interrelated efforts that can be pursued to improve the state of the art of criteria development and to resolve mission-peculiar criteria problems. Specifically, effort is needed to relate existing criteria to mission requirements, aircraft capability, and actual aircraft use to identify areas of inadequacy. Criteria need to be expanded to cover the increased capability of advanced aircraft concepts being considered for mobility and intelligence missions (i.e., compound helicopters, tilt rotor, etc.). Structural criteria must further be improved to make certain that the new aircraft concepts are designed for increased safety and survivability, reliability, maintainability, and adequate fatigue lives, and that the testing requirements will ensure that the design criteria have been met prior to fielding a new aircraft system.

The immediate goal is to establish criteria to overcome service-revealed deficiencies. Specific programs have been initiated or are planned for comparison of existing helicopter use with the original design criteria to establish a basis for specific improvements. Fail-safe criteria are being developed fo improved safety and survivability. Fatigue monit ring systems are being investigated for more accura e determination of

mission profiles and of fatigue damage across the fleet of Army aircraft. Testing methods and criteria are also being developed, including non-destructive testing, to evaluate more accurately the ability of new components and aircraft to live in the Army environment. The ultimate objective is a helicopter structural integrity program that will ensure adequate structural performance throughout the life of the aircraft. Chart ST–I summarizes the planned objectives and achievement goals in the structural criteria area.

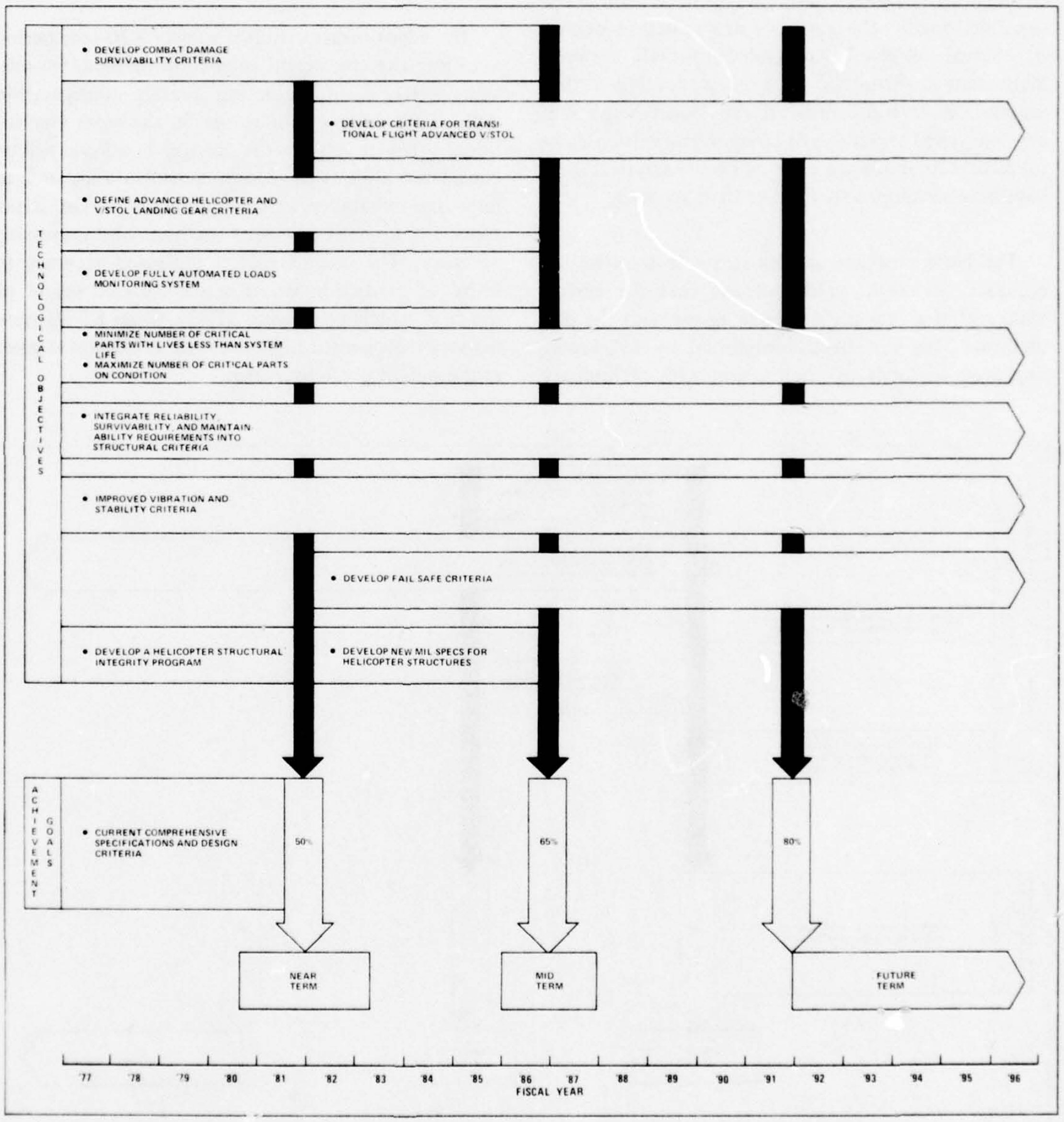


Chart ST–I. Summary of design criteria objectives and achievement goals.

WEIGHT PREDICTION

The ability to predict, in the early design phases, the weight of a new aircraft system at both the component level and on through the development of the total vehicle can influence the performance of the eventual flying vehicle as much as the aerodynamic calculations. Empirical trend curves have been developed that predict the weight of new systems based on the actual weight of equivalent aircraft systems. Mathematical formulas have been developed that account for several parametric variables. Where few if any equivalent structures or components exist, weight prediction methods are poor and few analytical tools have been developed to improve their accuracy.

The basic objective in this area is to improve the accuracy of weight predictions so that the performance of the first flight vehicle agrees with the predictions. This can be accomplished by developing improved methods in conjunction with preliminary design efforts that combine trend information with structural sizing based on quick loads and stress analysis. In the cases of a one-of-a-kind system where no empirical data are available, the method of estimating weights can be developed and consolidated with the structural component R&D efforts, including consideration of changing requirements for crashworthiness, survivability, maintainability, and component life.

The major thrust of activities over a 20-year period is to improve the weight prediction methods for missions systems, incorporating aircraft configuration such as tilt wing or tilt rotors. In the more conventional types of vehicles the changes in criteria will be considered along with design considerations, such as improved reliability versus minimum weight structures, for up-dating weights methods and improving accuracy. The overall goal is increased accuracy in terms of prediction versus actual roll-out weight of the first vehicle (see figure ST–2). Chart ST–II summarizes the planned objectives and achievement goals in the weight prediction area.

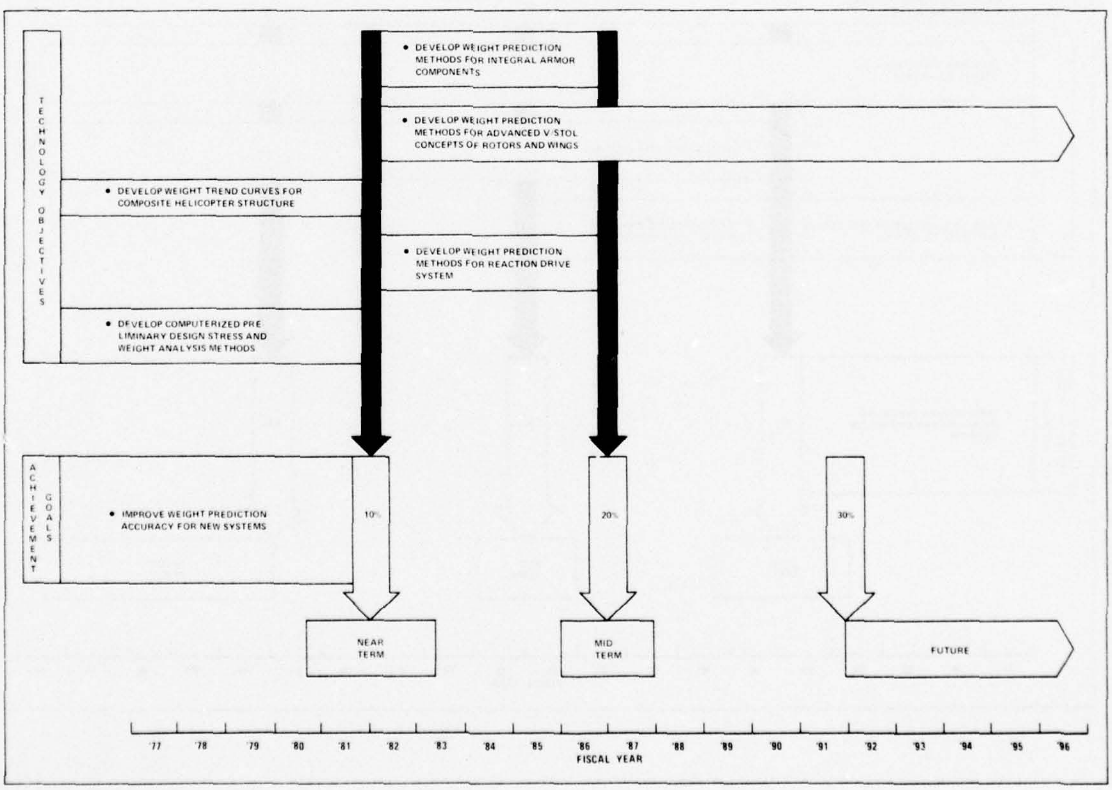


Chart ST–II. Summary of weights prediction objectives and achievement goals.

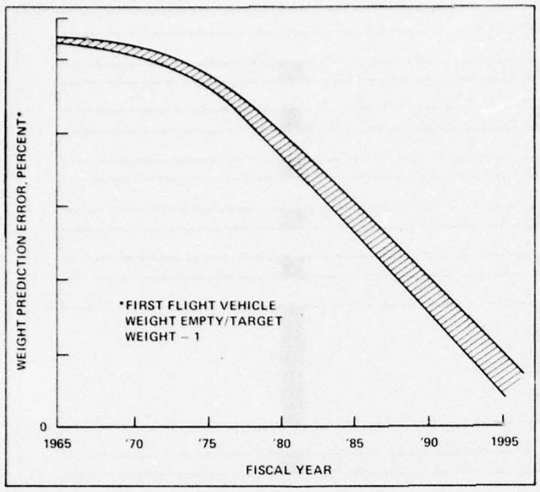


Figure ST–2. Weight prediction improvement goals.

MATERIAL ENGINEERING

The application of new and developing materials, both isotropic and anistropic, to aircraft is dependent on the ability to translate advances in basic material properties (i.e., shear strength, fatigue strength, etc.) into improvements in structural components. These improvements may be identified as reduced weight or vulnerability, increased life, safety, reliability, or reduced cost.

Research and development in fibrous composites and high-strength metals have made significant gains in such critical parameters as specific strength, stiffness, and fatigue strength. Varying degrees of success have been attained in applying these new materials to actual structures; cost and lack of confidence have been the designer's major barriers to achieving the full potential of the materials. (See In-Service Evaluation subsection.)

One of the basic objectives of R&D in this area is to evaluate the physical and mechanical properties of advanced materials for application to Army aircraft structures. These basic material properties must be translated to behavior characteristics of the overall component in terms of fatigue, fracture toughness, impact resistance, corrosion, and environmental degradation. Major considerations in the materials engineering area are efficient joining techniques, fabricability, inspectability, and costs. The cost consideration will not be limited to raw materials but will include manufacture and the effective life cycle cost.

Sufficient component development work will be accomplished to provide some confidence in the application of these materials to primary and secondary structures. Added confidence must be gained through service experience before the potential of these new materials can be realized in production aircraft systems, which is the primary goal of this effort.

Figure ST–3 shows the expected improvement trends in several key mechanical properties of materials. The expected increased use of composites in aircraft structure is shown in the middle curve.

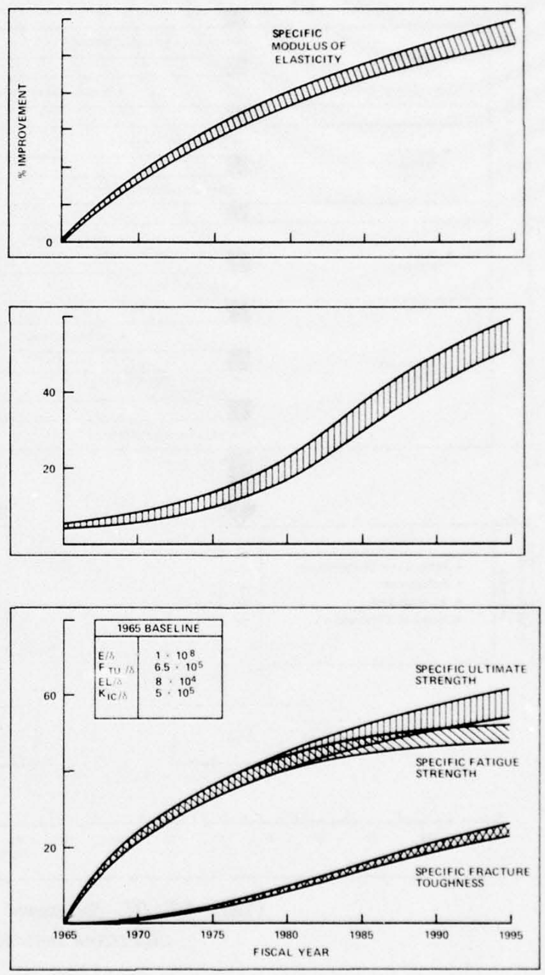


Figure ST–3. Material properties improvement and use goals.

Chart ST–III summarizes the planned objectives and achievement goals in the materials engineering development area.

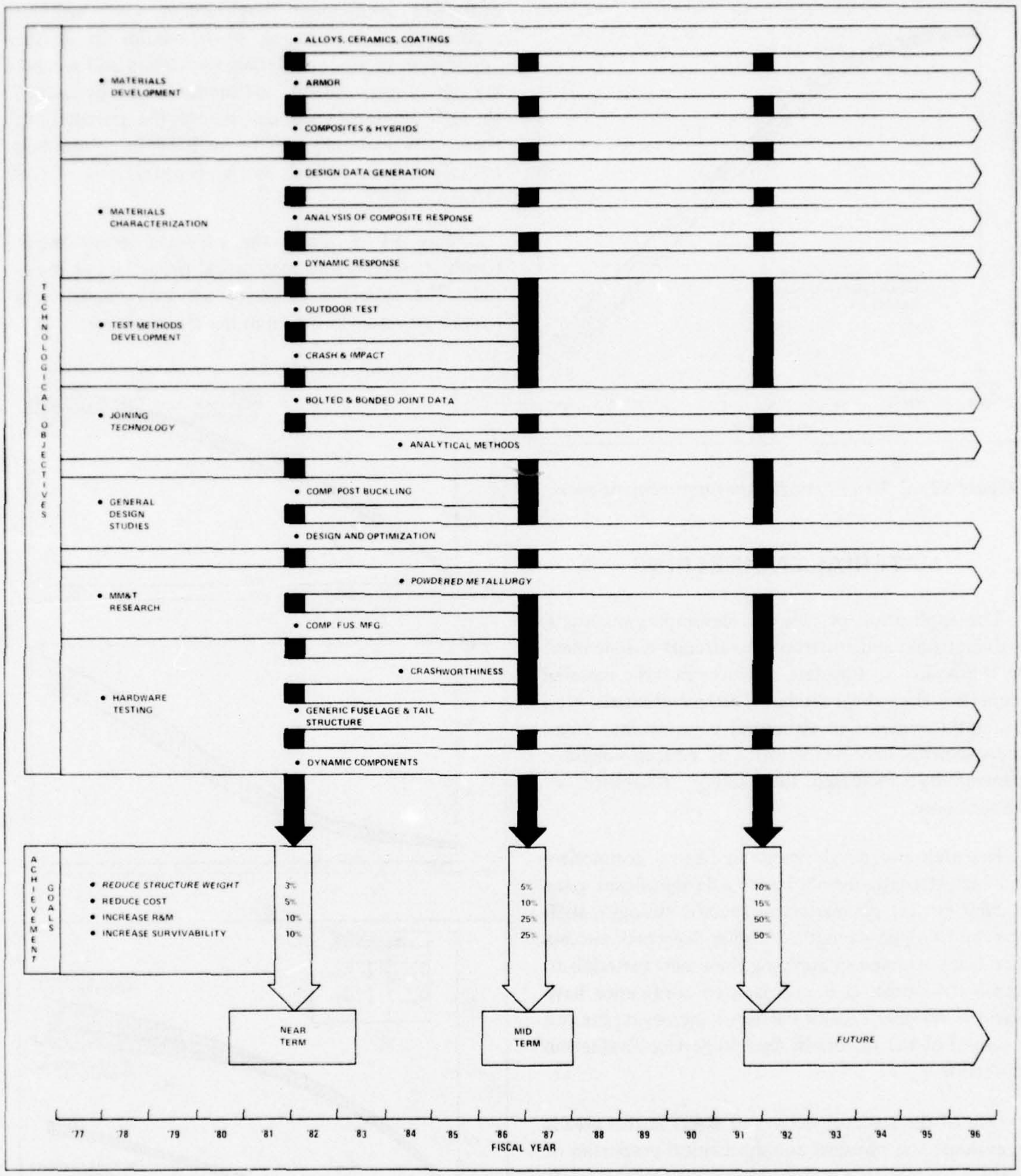


Chart ST–III. Summary of materials engineering objectives and achievement goals.

EXTERNAL LOADS ANALYSIS

Accurate prediction of the design loads the aircraft will experience in flight or in ground operation is required to ensure that the aircraft structure is sized properly to perform the design mission in the operational environment. Accurate estimates of external loads are required for structural stability analysis, development of fatigue spectra, development of internal loads, and stress analysis. The ability to predict these loads is required to ensure safety of flight and reduce the expensive engineering changes that result

when actual loads measured during flight test differ from original design loads.

The helicopter external loads are extremely difficult to predict because the rotor serves as the lifting system, propulsion device, and pitch and roll control device. The rotor is in a constantly changing aerodynamic pressure field that causes a complex and highly cyclic external loads situation. Analytical methods have been developed largely from empirical data for the steady-state dynamic loads on a hovering helicopter. The accuracy of existing methods is reduced as forward speed increases, and the ability to predict loads during maneuvers now amounts to extrapolating existing measured loads data.

The basic objective of R&D in external loads is to develop improved methods for predicting the loads acting on the vehicle throughout the flight and ground envelope to establish internal loads and stresses for structural design. The methodology must consider several degrees of desired precision in predicting loads and is highly dependent on the aerodynamics and dynamics R&D areas. Also important to the developing technology area are the loads associated with crash conditions, ballistic impact and internal explosions from enemy fire, nuclear blast, and ground handling. Computerized methods must be developed that can provide quick and accurate estimates of preliminary design loads. For detail design, methods must be developed that will analytically include all of the critical loading combinations and compute the most critical loading conditions for developing internal loads.

Because of the highly cyclic loading conditions caused by rotor rotation, most dynamic components are fatigue-critical. Since cyclic loads increase sharply with increasing speed and transient conditions, such as maneuvers, these conditions cause the most fatigue damage. For this reason, emphasis will be on methods for predicting transient loads. In order to cover transition regions, methods must also be developed for concepts such as tilt rotor and tilt wing vehicles. Correlation of predicted loads with model data and flight test data must be accomplished to substantiate the analytical methods. Flight loads measurement programs will be carried out with aerodynamic and structural instrumentation to improve the understanding of flight loads and to serve as the data base for correlation of prediction methods.

Figure ST–4 shows the expected improvement trend in external steady-state and transient loads prediction accuracy achievable from R&D in this area.

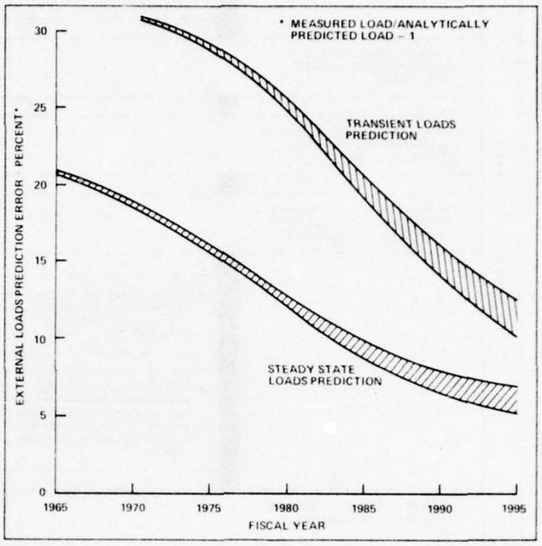


Figure ST–4. External loads prediction improvement goals.

Chart ST–IV shows a summary of research and development objectives with related achievement goals necessary to develop improved load prediction methods for all mission systems and to provide special load prediction capability to solve specific mission problems.

INTERNAL LOADS ANALYSIS

Methods for analyzing internal loads are the analytical tools used to distribute external loads throughout the complex internal structural configuration. These internal loads are the basis for structural component design and detail static and fatigue analysis. Each individual load must be reacted to ensure that the total structural configuration is in equilibrium.

Internal loads analysis methods for static conditions have reached a high level of refinement. The primary method uses computerized finite-element techniques that permit accurate analysis of complex redundant structures. Dynamic response to vibratory loading and structural instabilities can also be predicted, although significant inaccuracies have been noted.

Although the analytical techniques now provide excellent capability, they are not configured for use

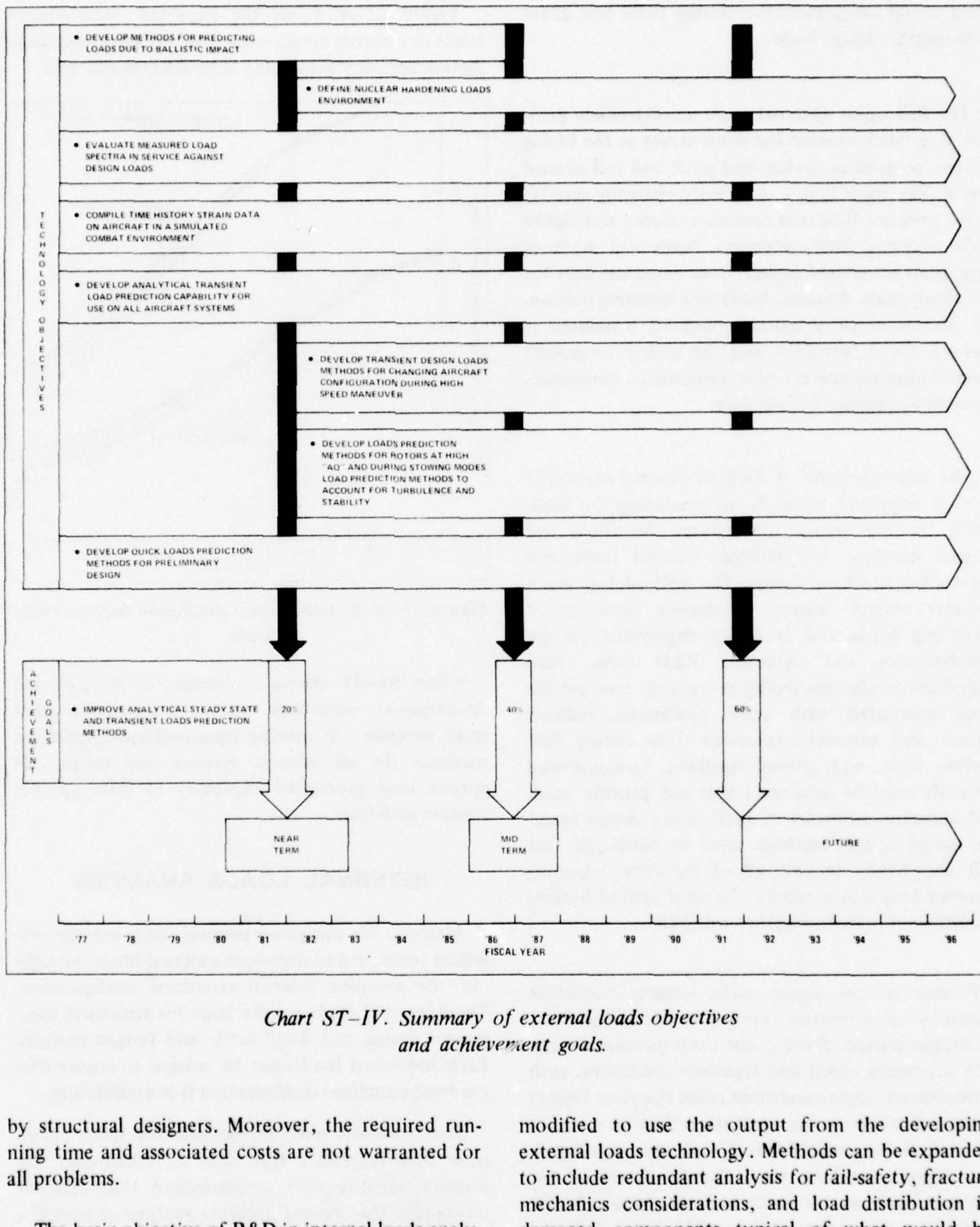


Chart ST–IV. Summary of external loads objectives and achievement goals.

by structural designers. Moreover, the required running time and associated costs are not warranted for all problems.

The basic objective of R&D in internal loads analysis is to extend the highly efficient analytical techniques developed by NASA and other governmental agencies to problems that are unique to Army aircraft. Simplification procedures can be developed to provide quick and inexpensive capability for the structural designer. The analytical methods can be modified to use the output from the developing external loads technology. Methods can be expanded to include redundant analysis for fail-safety, fracture mechanics considerations, and load distribution in damaged components typical of what would be expected from combat damage.

Figure ST–5 shows the expected increase in the use of advanced analytical methods on Army aircraft design problems. The increased use reflects progress in adapting these programs to the needs of the

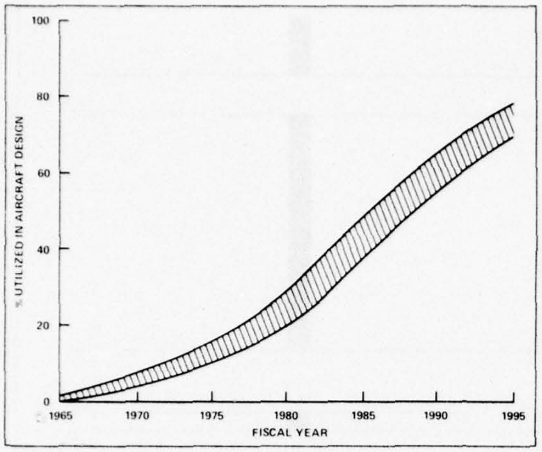


Figure ST–5. Use of improved internal loads methods in Army aircraft design.

designer, and in the ability to optimize the structural design for varying loading considerations including battle damage, failures in fail-safe components, etc.

Chart ST–V shows the research and development objectives summary with related achievement goals needed to expand the internal loads analysis methods for application to Army aircraft and solve specific mission problems.

FATIGUE AND FRACTURE MECHANICS

Primary components of helicopter and V/STOL dynamic systems are largely designed to fatigue loading conditions. Fatigue life is computed on the basis of probabalistically high loads and low fatigue strengths to minimize the potential for catastrophic failure. When the predicted fatigue life, measured in terms of flight hours is reached, the component is removed and discarded; as a result, components with a considerable service life remaining may be removed. Conversely, catastrophic fatigue failures have occurred in service because of unexpected causes, such as design errors, manufacturing errors, or misuse.

Fatigue life computation procedures used on Army aircraft vary from contractor to contractor because of different assumptions and degrees of conservatism. Some standardization of analytical methods is needed to evaluate several design configurations and thus ensure an equitable basis in terms of safety or reliability. This affects structural weight, performance, and costs for the aircraft systems being considered. Service experience indicates that there are enough fatigue failures and enough parts with extremely limited service lives to cause concern about some of these procedures. Miner's rule of cumulative damage is almost universally used in the industry, although considerable doubt has been cast on its validity in the high-cycle, low-amplitude fatigue environment critical to helicopter and V/STOL concepts.

Service-use spectra, which are the basis for fatigue criteria, are not well-defined and are nonexistent for proposed new aircraft systems, such as tilt wing or tilt rotor aircraft. The combination of increased performance capability and new mission requirements makes definition of the fatigue design spectrum difficult within the state of the art. Some progress has been made in developing fracture-control methods by applying fracture-mechanics theory to the prediction of crack growth in a dynamic loads environment, but not enough to establish fail-safe criteria required for critical components.

The basic objective of R&D in this area is to develop advanced methods of computing fatigue lives of components subjected to a complex, highly cyclic loading environment. The methods must be flexible enough to account for high-cycle and low-cycle spectral loads peculiar to helicopters and rotary wing derivatives. The prediction of structural degradation in metals will consider not only fatigue to the initiation of a crack, but also propagation of a crack from initial damage point, load cycle by load cycle, to an unstable crack condition. In composite materials, fatigue damage is more complex than in metals and can occur in numerous modes such as transverse cracks, axial cracks, and delamination. Methods will be developed to predict the mode of fatigue damage, when and where it will occur, how fast it will propagate, and its effect on residual strength. This ability to predict, coupled with fatigue detection devices and cost considerations, will provide for the establishment of realistic fail-safe criteria. Methods for developing accurate fatigue spectra for new aircraft systems can be developed in conjunction with external and internal loads methods to ensure safe, reliable systems.

Both the methods and effectiveness of fatigue analysis and life substantiation now used by the helicopter and V/STOL aircraft industry vary from company to company. A program has been initiated which will ultimately lead to establishment of a standard method for Army programs. Fatigue testing will be evaluated to ensure test procedures that produce high-confidence, reliable components, that reduce the

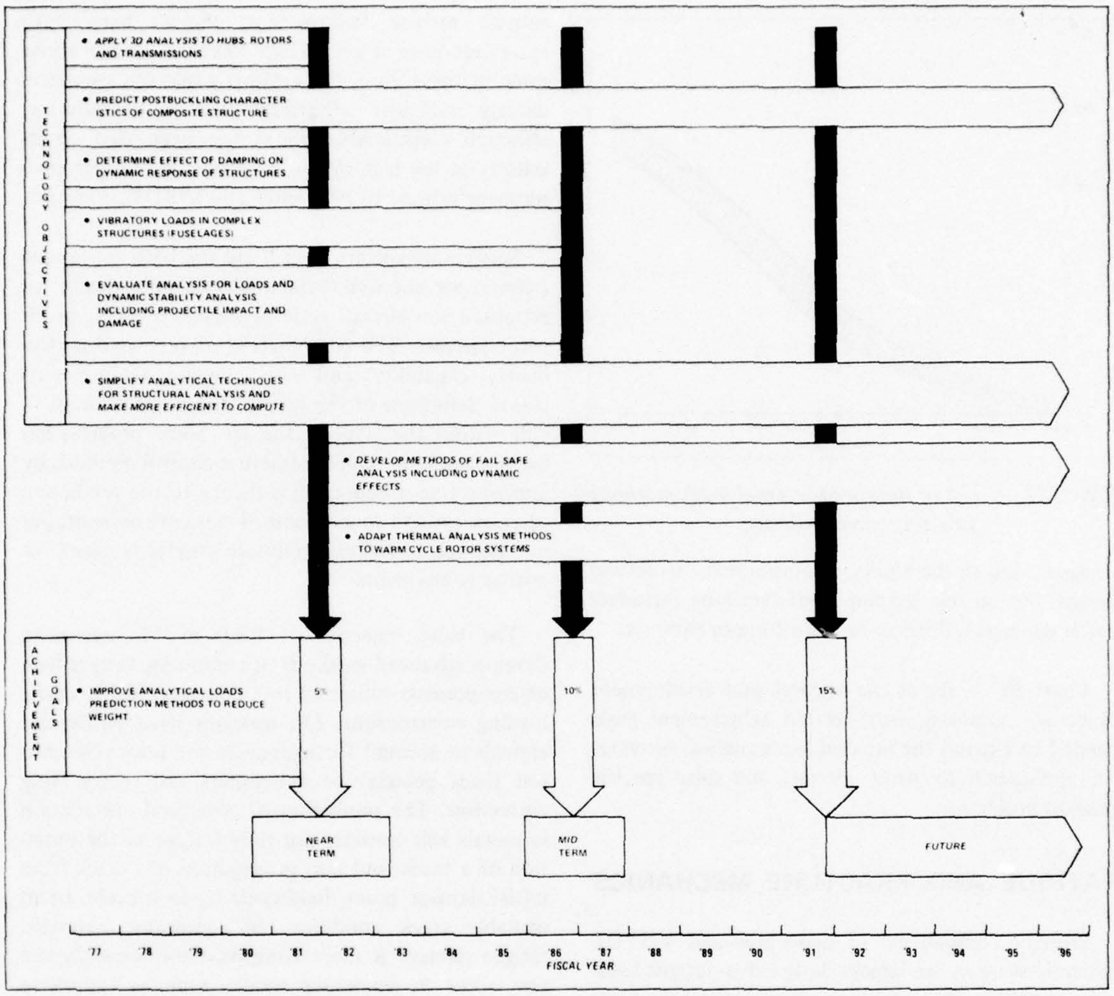


Chart ST–V. Summary of internal loads objectives and achievement goals.

potential for unexpected failures in the field. Correlations will be made between aircraft performance capability and actual use in the field to provide a rational basis for establishing fatigue spectra in the future. Fatigue monitoring systems are being developed to record aircraft use as it affects structural integrity and to serve as the criteria for fatigue critical part removal.

Figure ST–6 shows the improvements sought, in accuracy of predicting damage propagation, to serve in establishing fail-safe criteria.

The R&D efforts required to improve the state of the art of fatigue analysis are shown in chart ST–VI with corresponding achievement goals.

STRUCTURAL CONCEPTS

Advanced structural concepts are developed to improve one or several performance features of aircraft systems. These include reduced weight, vulnerability, maintenance, cost, and increased reliability and safety. The structural concepts efforts relate directly to components and serve as the focal point for the other structures subdisciplines. The advanced structural components demonstrate the translation of technological advances in materials, analysis methods, and criteria into a practical hardware improvement. Thus the component design, fabrication, and testing programs establish the confidence for putting technology on-the-shelf, a basis for estimating the cost

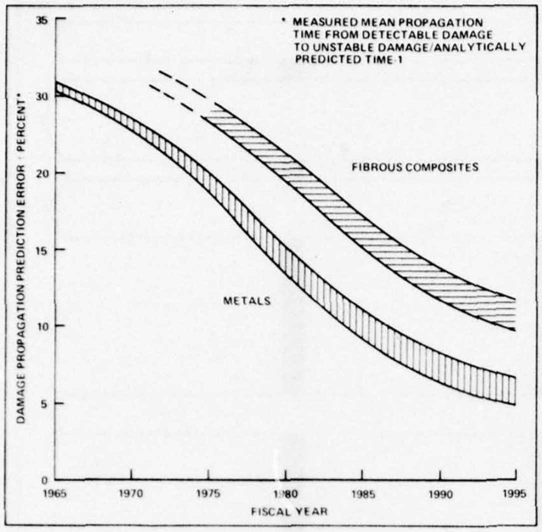


Figure ST–6. Fracture mechanics goals.

effectiveness of the advanced technology and an indicator of where additional work is required.

In most cases, structural concepts in use in the Army inventory reflect a 20-year-old state of the art. The concepts do not reflect the latest advances in crash attenuation techniques, ballistic tolerance, or the efficient use of new materials. Airframes hand-built from many small detail parts, incur excessive production costs. Considerable work has been done in-house and in the industry to apply advanced fibrous composites to structural components. Because of the design flexibility realizable from those materials that can be tailored to specific stiffness and strength needs, the major efforts to date have been on rotor blades. Ballistic-tolerant flight control components have been demonstrated. Some studies have been made of applications of new concepts to large fuselage and engine components. Increased confidence is needed to commit the primary structure of developmental aircraft systems to this technology. Uncertainties over the production cost of these new concepts have also limited their use.

The basic objectives of R&D in this area are to demonstrate, to an acceptable level of confidence, advanced structural concepts applied to representative hardware components. This effort should effectively use the advancement in the other structures subdiscipline areas as well as safety and survivability, reliability and maintainability, and other related disciplines as applicable. Since this serves as the primary area for putting structures technology on the shelf, it must be a phased program applying basic research accomplishments through design studies to demonstrate concept feasibility. The promising concepts should then go to detail design, fabrication, and test in an advanced development effort. The results of the exploratory development should provide the basis for advanced development and demonstration showing relevance to a specific planned aircraft system or improved capability for an existing system. Because of the combat mission of Army aircraft, fail-safe configurations and combat damage survivability (including nuclear hardening) are key structural features that will be emphasized as objectives of the structural component concepts.

Specific efforts can include the development of fail-safe structural concepts for the dynamic system as well as for the airframe. Advanced composite rotor blades, rotor hubs, and fuselage sections will be designed, fabricated, ground tested, and flight tested to demonstrate the feasibility of these concepts on a component basis to assess the advantages of weight savings, producibility, and potential cost savings. Figure ST–7 shows expected improvement trends in weight savings in several aircraft subsystems achievable from research and development in advanced structural concepts. The net results of improvements in structural efficiency may not result in weight savings but rather in increased structural capability (i.e.,

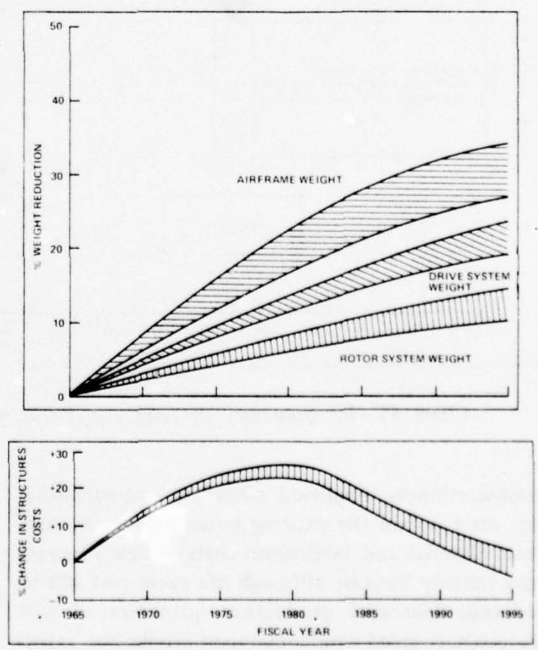


Figure ST–7. Structural concepts goals.

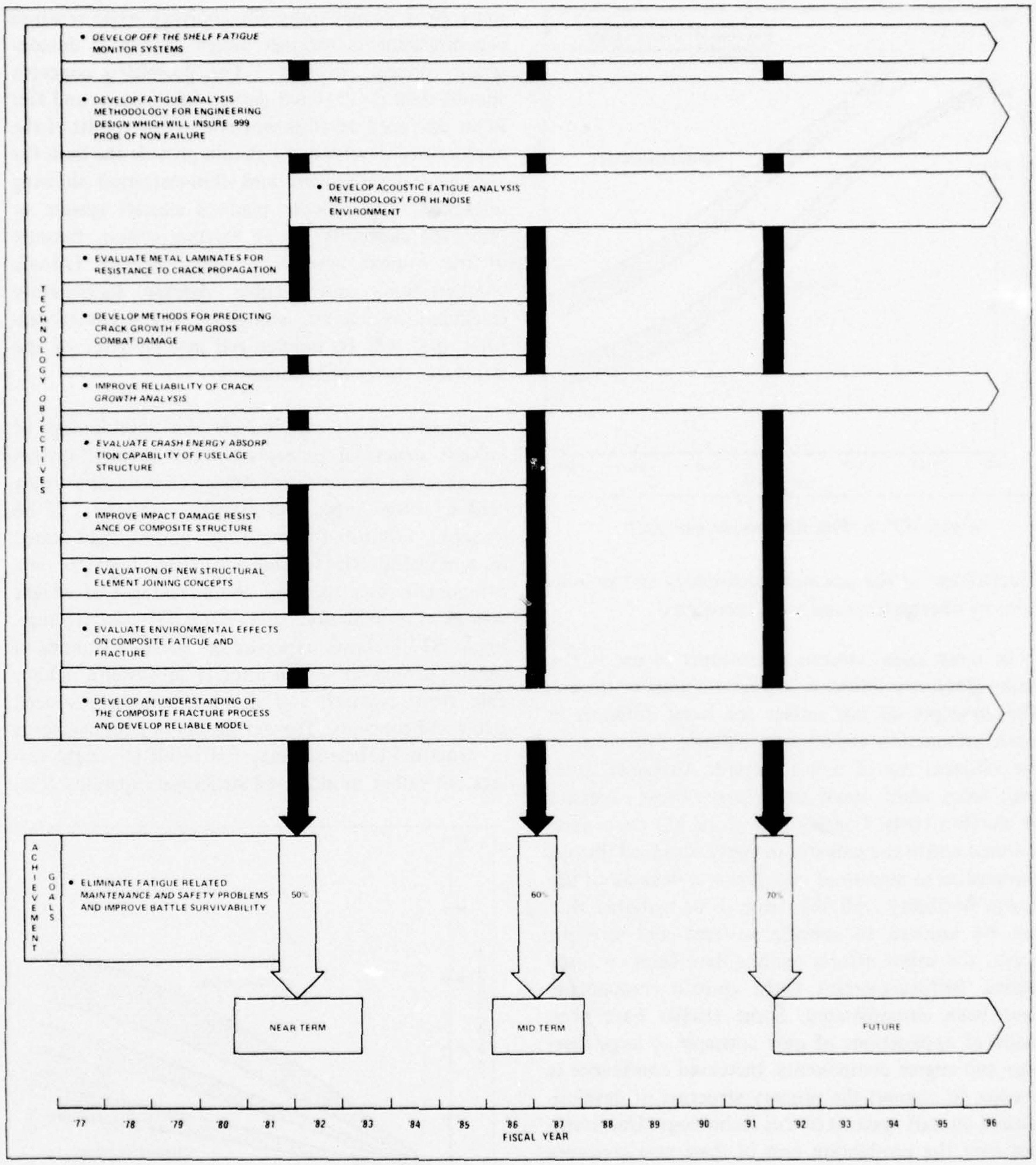


Chart ST–VI. Summary of fatigue and fracture mechanics objectives and achievement goals.

crashworthiness, improved reliability and survivability, etc.) within the existing structural weight fraction. Material and fabrication costs of new concepts may initially increase although life cycle cost will be reduced. Increased production quantities of new materials, coupled with component production experience will, in the near future, reduce the initial cost.

Chart ST–VII summarizes the R&D objectives and achievement goals in the area of new structural concepts.

IN-SERVICE EVALUATION

Since the introduction of advanced composites over a decade ago hundreds of airframe components

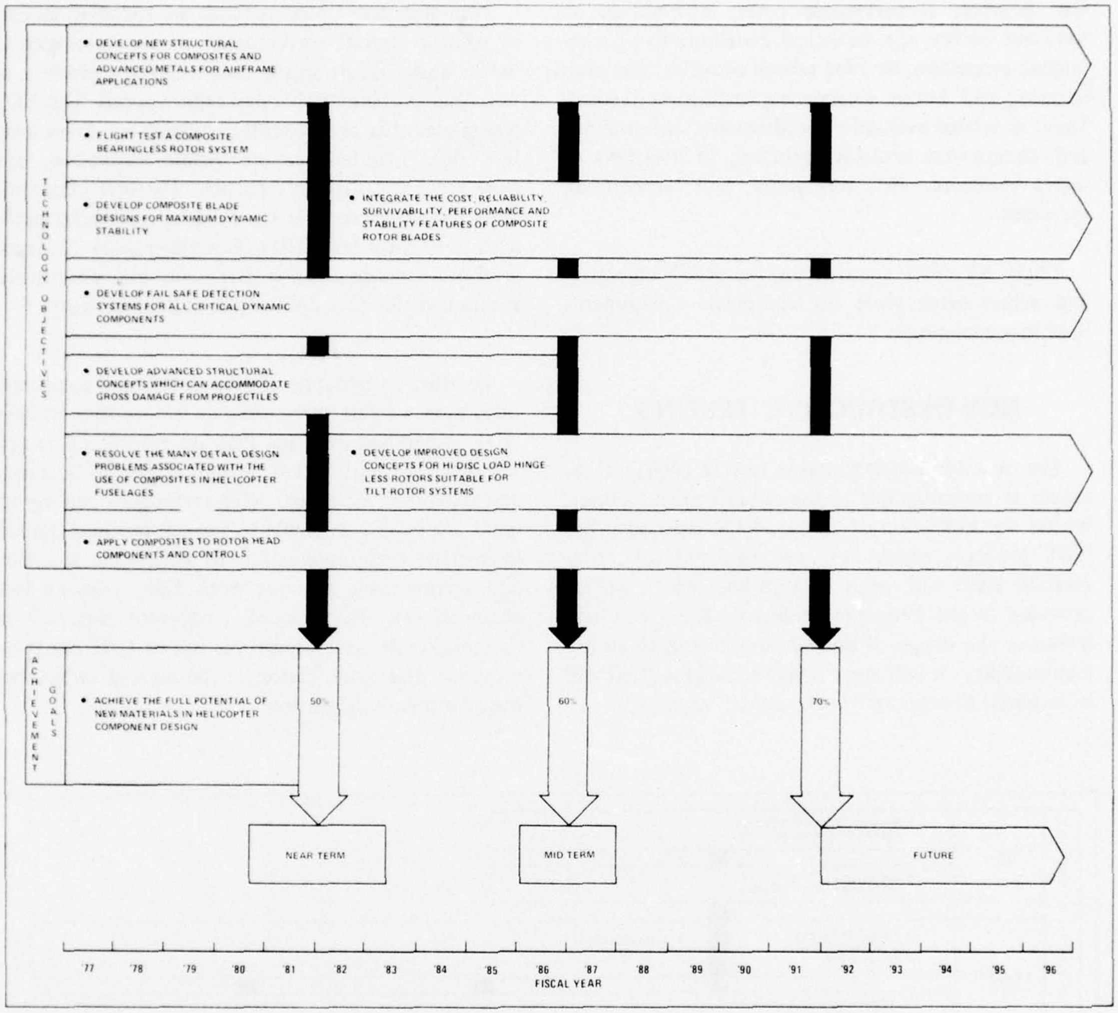


Chart ST–VII. Summary of structural concepts objectives and achievement goals.

have been made from these materials. These components have involved many combinations of materials, design concepts and fabrication methods. Most have been built in small quantities for test purposes. While this R&D work is valuable it cannot be expected to provide an adequate base of experience for evaluating these components in service or for estimating realistic production and inspection costs. Estimating fabrication learning curves, volume production problems, tooling, maintenance, repair requirements, environmental degradation, in-service maintenance, foreign object damage, reliability, etc., all require an extensive history of flight service experience on similar parts before newer materials and structural concepts can be committed to production. The objective of this new technology area is to provide this experience in the safest and most economical way, namely, by building confidence and accumulating data from limited production runs of less expensive flight service components that are removable and readily serviceable.

Beginning with secondary and non-safety-critical parts, and progressing to more critical primary structure, the essential flight service experience can be gathered in a systematic manner. Any mistakes or oversights in the early applications of these materials/concepts will be more likely to be discovered before risking a major loss of system effectiveness or excessive operating costs. The flight service programs can

also provide, at reasonable costs, information on wear-out curves, the statistical distributions of component properties, detailed service histories, user evaluations, and better engineering inspection records. These in-service evaluations will involve both military and commercial vehicles operating in locations of severe moisture, dirt, salt spray, and temperature extremes.

Chart ST–VIII summarizes the R&D objectives and achievement goals for composite components in-service evaluation.

NON-DESTRUCTIVE TESTING

The use of non-destructive testing (NDT) techniques is currently left to the aircraft manufacturer, within the limitation of the available methods. The NDT program which has been initiated for Army aviation R&D will result in guidelines which will be provided to the helicopter industry. These will help influence the design of critical components to ensure inspectability. It will also provide techniques that will be required to support "on-condition" removal.

Non-destructive test methods are specified as part of routine aircraft maintenance or are developed to detect a specific structural flow which is a problem or potential problem with a particular aircraft. The NDT techniques that are currently available for Army aviation field maintenance are visible inspection, dye penetrant, and magnetic particle. Portable ultrasonic units have been used in the field for particular problems (540 rotor blade, AH-1G landing gear). At depot level other methods, including X-ray and ultrasonics, are used at the discretion of the individual depot.

In order to maintain aircraft safety and to achieve maximum aircraft utilization, it is necessary to have NDT techniques available that are capable of detecting flaws or defects with a high degree of accuracy and reliability. Although NDT techniques and equipment are readily available to inspect for most defects in metals, their application to helicopter structure and components has not been fully pursued (see figure ST–8). The use of composite materials in future aircraft will require the use of different techniques or the modification of the current techniques used for metals inspection.

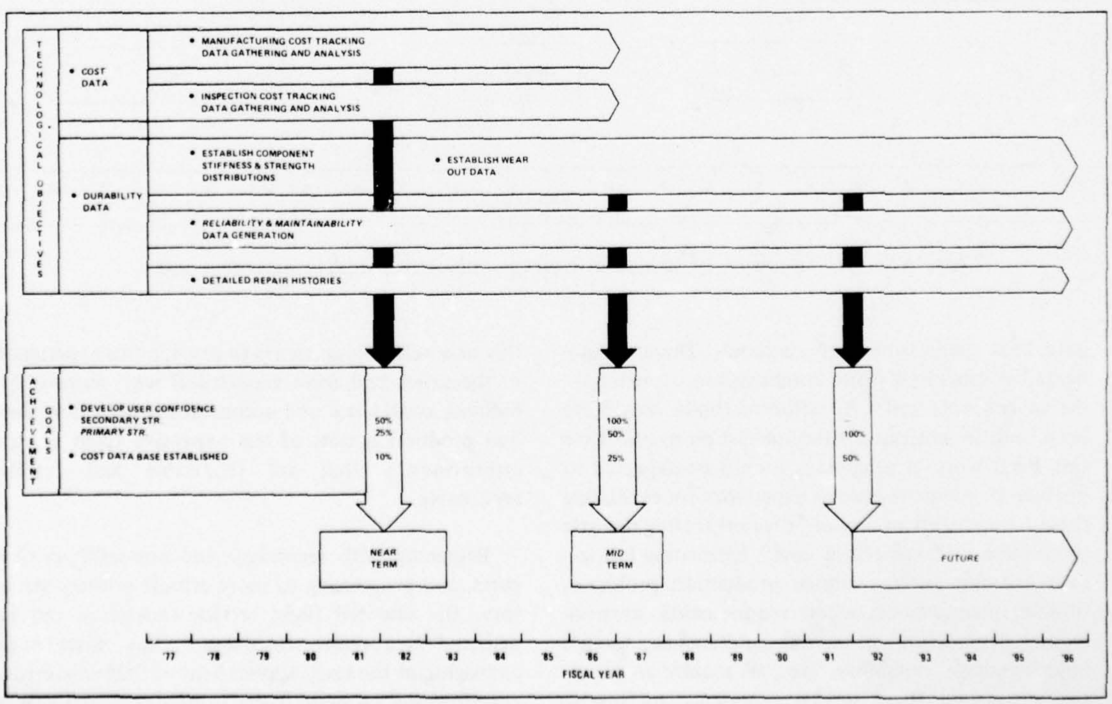


Chart ST– VIII. Summary of in-service evaluation objectives achievement goals for composite components.

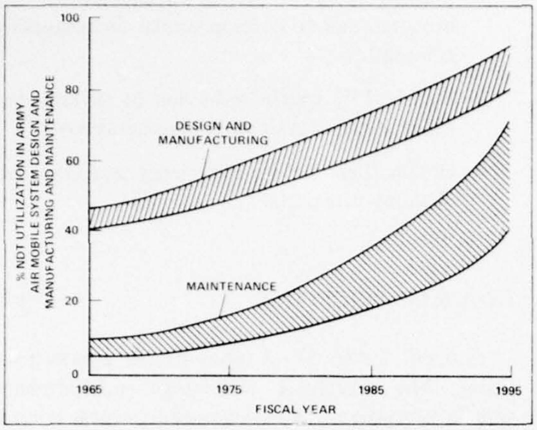


Figure ST–8. Increasing usage of NDT techniques.

The basic objective of R&D in this area is to develop the technique, utilizing state-of-the-art NDT equipment, for the evaluation of existing and next-generation (composite) Army aircraft structures. These techniques must be available so that they can be utilized during the complete aircraft life cycle, including manufacture, routine maintenance, repair, and component retirement.

Chart ST–IX summarizes the R&D objectives and achievement goals in the area of non-destructive testing.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in the Technology Introduction section of the Plan. This section applies that process

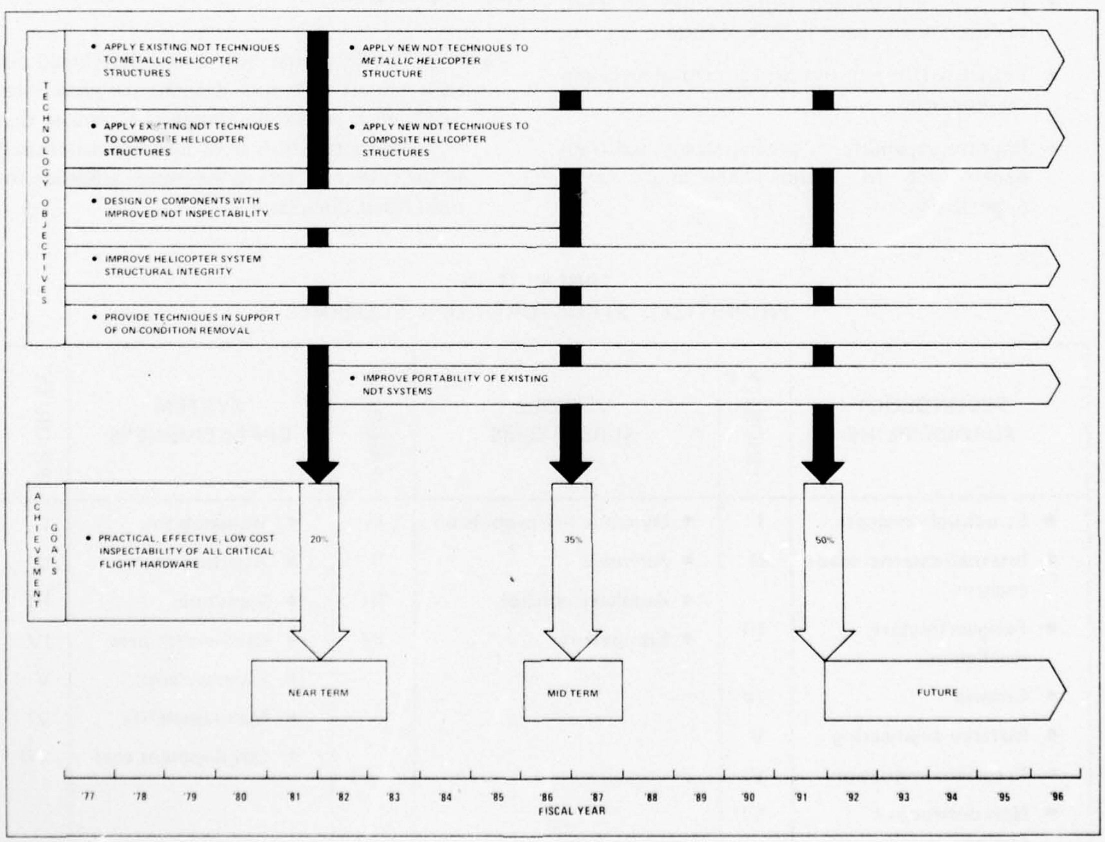


Chart ST–IX. Summary of non-destructive testing objectives and achievement goals.

to the structures discipline. The OPR is not an objective of the Plan, but is provided to show the procedure used in the selection of programs within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the structures discipline can be established from the near-term objectives and achievement goals listed in charts ST–I through ST–IX. The objectives are of two types. First, those that will result in direct improvement of one or several key parameters and second, those that improve prediction capability and produce indirect performance and cost improvements. The near-term structures objectives are as follows:

- Develop improved structural design concepts that take full advantage of composite material behavior.
- Increase on-condition parts to 40% of total. Reduce low-life parts to 20% of total.
- Realize a 10% improvement in critical mechanical properties.
- Improve capability to predict steady and transient loads to within ±18% and ±28%, respectively.
- Improve ability to predict damage growth rates in metals and to develop similar techniques for composites.
- Realize 15% weight reduction in airframe and 8% in dynamic systems at reasonable cost.
- Obtain flight service experience and cost data on composite parts.

PROGRAM PRIORITIES

General. Table ST–A presents, in a prioritized listing, the structures technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The structures technology subdisciplines are represented by the following major topical areas:

- *Criteria.* Structural criteria are developed for each aircraft system to describe the procedures to be observed by the designers to ensure that structural integrity is built into and maintained in the system. It acts as the overall guideline for most other disciplines.

TABLE ST–A
PRIORITIZED STRUCTURES OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Structural concepts	I	• Dynamic lift/propulsion	I	• Vulnerability	I
• Internal/external loads analysis	II	• Airframe	II	• Attrition costs	II
• Fatigue/fracture mechanics	III	• Auxiliary control	III	• Signature	III
• Criteria	IV	• Equipment	IV	• Crashworthiness	IV
• Material engineering	V			• Flyaway cost	V
• In-service evaluation	VI			• Maintainability	VI
• Non-destructive testing	VII			• Development cost	VII

- *Material Engineering.* Material Engineering is concerned with construction materials, their evaluation, use in design, fabricability, and limited hardware evaluation.

- *Internal/External Loads Analysis.* Design loads prediction methods pertain to the ability to accurately predict the magnitude of forces to which the aircraft is subjected in its lifetime. The forces must be defined in terms that ensure a low probability of their being exceeded, and that may be used and verified by the designer through tests. The loads may be externally applied – for example, aerodynamics, inertia, ground contact – or internally applied – for example, stress distribution through complex redundant structure.

- *Fatigue/Fracture Mechanics.* Fatigue/fracture methods pertain to the ability to accurately predict the ability of aircraft structures to resist fatigue degradation and to be tolerant of structural damage. It is the rational coalescence of materials allowables and design loads methods to ensure safe life/fail safe aircraft systems.

- *Structural Concepts.* Advanced structural concepts pertain to the ability to combine the best of the materials and methods described above into new conceptual systems or subsystems with unique capability in terms of reduced weight and cost, increased survivability, maintainability or durability, or a combination of these.

- *In-Service Evaluation.* This area involves the introduction of new materials into regular service through short or limited production runs with close subsequent monitoring of performance histories.

- *Non-Destructive Testing.* Non-destructive testing pertains to the development of techniques, utilizing state-of-the-art NDT equipment, for the evaluation of existing and next generation (composite) Army aircraft structures.

Vehicle Subsystems. Vehicle subsystems, as related to structures technology, are categorized as follows:

- Dynamic lift/propulsion elements – rotors and propellers.

- Auxiliary control elements – tail rotors and control surfaces.

- Nondynamic airframe elements – fuselage, wings, and landing gear.

- Equipment elements – equipment integration.

These are the vehicle subsystems that produce the major structural design requirements and the most impact on structural integrity.

System Effectiveness. In the area of system effectiveness, the primary impact of structures technology is on life cycle costs and vehicle effectiveness. In the life cycle cost area, structures play a key role in development, flyaway and attrition costs; and in vehicle effectiveness, structure is most prominent in determination of vehicle vulnerability, crashworthiness, signature, and maintainability.

Priorities. With reference to table ST–A, the structures subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the structures technology R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 structures technology development program.

Assessment of the priority listing in table ST–A and the near-term objectives listed in charts ST–I through ST–IX indicates that the first major thrust is to develop advanced rotor system concepts to reduce vulnerability due to hostile environment. The rotor system, that is, hub and blades, provides most of the lift/propulsion and control to VTOL aircraft and, at the same time, is directly subjected to the worst natural and man-made hostile environment. Service data indicate a great need for improvement in these systems. A weight improvement potential is anticipated in this area and, through application of advanced materials, large strides can be anticipated in damage tolerant design. Basic research efforts and component exploratory development programs have progressed to the point that the next logical step is to demonstrate the potential payoff of this technology through advanced development programs. This payoff will be reflected in increased ballistic tolerance and safety, while reducing radar signature and maintenance. The advanced concepts will permit reduced

vehicle life cycle costs resulting from reduced weight, number of parts, and manufacturing man-hours.

The second major thrust is to develop advanced airframe system structural concepts to reduce vulnerability due to hostile environment. Service experience clearly indicates the need for this improvement. Although the airframe is not as critical a problem as the rotor system, the potential payoff (15% airframe weight reduction vs 8% for dynamic systems) is greater and justifies concerted effort in this area.

LABORATORY PROJECTS FOR FY78 IN STRUCTURES

INTRODUCTION

Structures technological development effort is directed toward research (6.1), exploratory development (6.2), and advanced development (6.3) to increase knowledge and demonstrate advanced aircraft technology in the structures discipline. This effort is conducted primarily by the Structures Laboratory, NASA-Langley Research Center, Hampton, Virginia and the Applied Technology Laboratory, Fort Eustis, Virginia. The Structures Laboratory deals primarily with 6.1 and exploratory 6.2. The Applied Technology Laboratory deals primarily with 6.2 and nonsystems 6.3 work.

Programs at the Structures Laboratory are primarily in the areas of internal loads analysis, fatigue, fracture mechanics, material engineering, and in-service evaluation. Programs at the Applied Technology Laboratory are primarily in the areas of structural criteria, external loads analysis, materials allowables, and advanced structural concepts.

The distribution of programs between the two directorates is influenced in part by the capabilities of the NASA-Langley Structures Research Laboratory and the structures testing facilities at Fort Eustis.

DESCRIPTION OF PROJECTS

Research in Structures. Project 1L161102AH45-TA III is a basic research effort providing the fundamental structures and materials application technology necessary for demonstration of the significant improvements possible in rotary wing safety, survivability, and mission effectiveness through an effective structures program. The efforts under this project are directed toward (1) the development of analytical techniques for complex structures, including metals, composites, and metals reinforced with composites; (2) the development of the fatigue characteristics of these structures; and (3) the demonstration of the utilization of these materials on rotary wing aircraft. The fracture characteristics of these materials will also be determined in order to develop adequate fracture control procedures and techniques. These research objectives are accomplished by in-house research programs conducted by the Structures Laboratory in joint participation with the NASA-Langley Research Center and by in-house research conducted by Watervliet Arsenal.

Structures Technology. Project 1L262209AH76-TA II is an exploratory development effort to develop and demonstrate the technologies, techniques, and design criteria necessary to provide adequate performance, structural design loads, aeroelastic stability, static and fatigue strength, and structural integrity for the Army's rotary wing missions and to improve the capability to analyze and predict these characteristics to existing and future aircraft. This technology will increase the aircraft's availability and survivability as well as provide for improved operational effectiveness and mission capability of Army aviation systems. Research from this project will provide part of the analytical, design, and test techniques necessary for valid prediction and analyses of the performance, structural design loads, aeroelastic stability, static and fatigue strength, and structural integrity, thereby increasing the potential of achieving design-to-cost objectives within the Army. These research objectives are accomplished by conducting analytical, structural, and wind tunnel, and flight test investigations. Foreign state-of-the-art trends and potential threats to the present and future material or systems throughout the R&D cycle have been considered.

Advanced Aircraft Structures. Project 1L263211DB41 is an advanced development effort to develop and demonstrate advanced structures technology, test techniques, and evaluation criteria to provide advanced design concepts and structural components with increased survivability, improved reliability and maintainability, and greater mobility for Army aircraft. Advanced design concepts and composite materials will be evaluated in rotor blades, rotor hubs, landing gears, airframes, and other structural components to provide the necessary data and technology to move into engineering development. Research from these efforts will provide analytical,

design, and test techniques for valid prediction and analysis of the structural performance, manufacturability, and structural integrity, thereby increasing the potential of achieving design-to-cost objectives within the Army. These research objectives are accomplished by conducting analytical, structural, wind tunnel, whirl, and flight test investigations. Foreign state-of-the-art trends and potential threats to present and future material or systems throughout the R&D cycle have been considered.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the structures R&D efforts as presented in the technical discussion are shown and discussed in the Resources Required section of the Plan. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.1, 6.2, and 6.3 structural R&D efforts are shown in table ST–B. Included in the table is the ratio of the structures efforts to the total 6.1, 6.2, and 6.3 Laboratories R&D efforts.

TABLE ST–B

STRUCTURES TECHNOLOGY FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78	
6.1	1L161102AH45-TA III	1297	26%
6.2	1L262209AH76-TA II	2875	17%*
6.3	1L263211DB41	350	4%

*Does not include Project 1L262201DH96 Aircraft Weapons Technology funds.

INTRODUCTION

TECHNOLOGICAL DISCUSSION

GENERAL

AEROTHERMODYNAMIC COMPONENTS

CONTROLS AND ACCESSORIES

MECHANICAL ELEMENTS

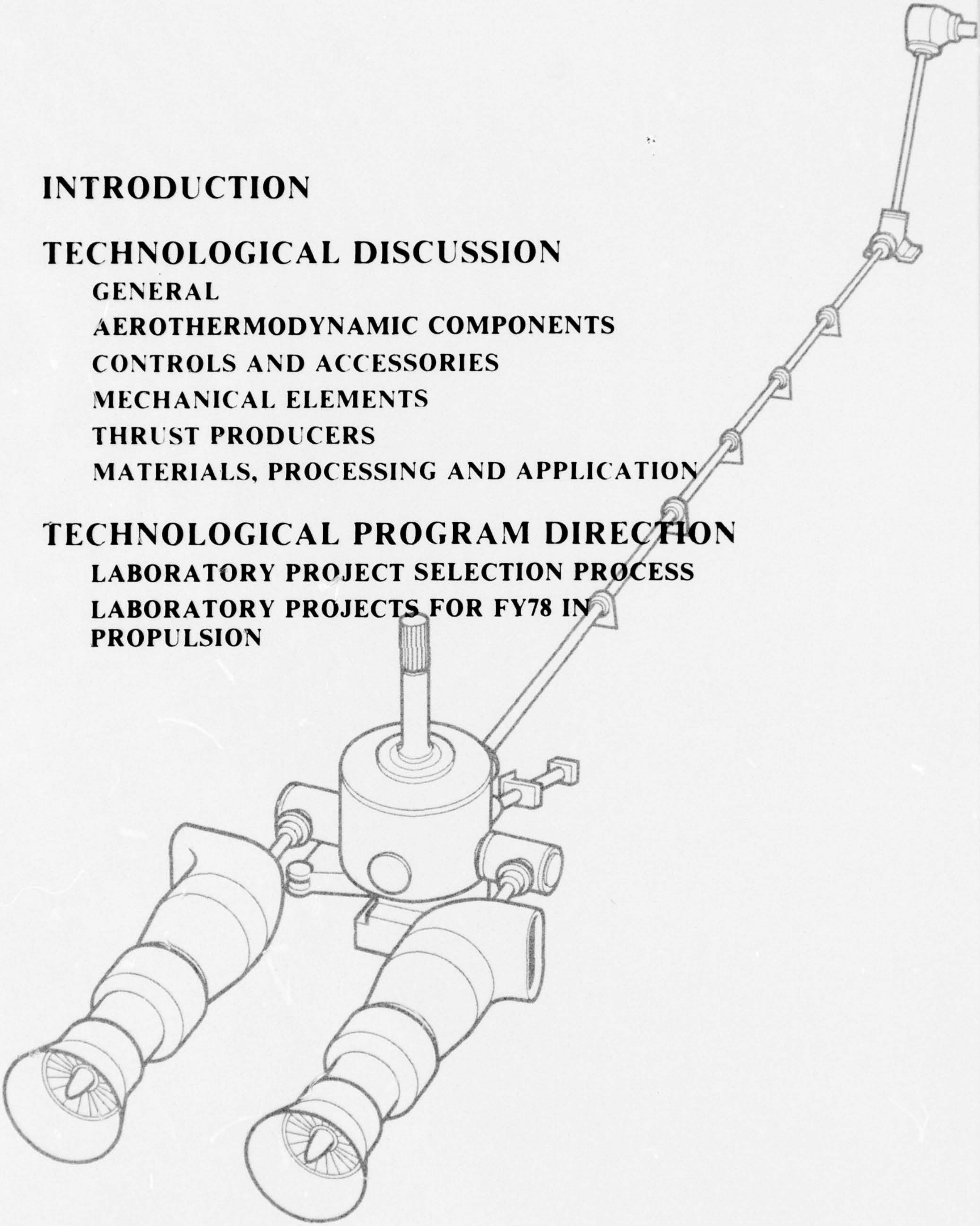
THRUST PRODUCERS

MATERIALS, PROCESSING AND APPLICATION

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

LABORATORY PROJECTS FOR FY78 IN PROPULSION



INTRODUCTION

Propulsion system technology provides the mechanisms and processes by which the chemical energy in fuel is converted into forward thrust and/or lift. The process normally involves one or more of the following conversions:

- Chemical energy into heat
- Heat into mechanical energy
- Mechanical energy into thrust and/or lift

The effect of propulsion system technology on the aircraft is profound. Assuming that an engine with adequate power can be provided, the performance, payload, and range of the aircraft are directly related to the weight and efficiency of the propulsion system. Increases in system weight will result in reductions in performance, payload, range, or combinations of the three. Reductions in system efficiency will result in the use of more fuel to perform the mission. In addition to extra fuel usage, the weight of the additional fuel and associated tankage will result in penalties on performance, payload, and range.

The propulsion system also has a significant effect on the life cycle cost of the aircraft. Recent analysis of existing helicopters indicates that, for a typical helicopter, the engine and transmission account for approximately one-third of the acquisition cost. Acquisition cost represents about one-fifth of the aircraft life cycle cost (operational cost makes up the remainder); it follows that acquisition of the propulsion system represents about 6 percent of the total aircraft life cycle cost. Maintenance of the engine and transmission (a direct function of their reliability and maintainability) accounts for about 26 percent of the aircraft operational cost, and consumables, primarily fuel (directly influenced by propulsion and drive train efficiency), accounts for one-third and will increase in proportion to future increases in fuel cost. Therefore, 60 percent of the aircraft operational cost is directly related to the propulsion system technology level. This represents 48 percent of the life cycle cost. Considering both acquisition and operating cost, more than 50 percent of the total aircraft life cycle cost is related to the technology level of the propulsion system.

The missions and aircraft that constitute Army aviation activities are described in the Airmobile Systems Section of this plan. Since the Army operates in the V/STOL and low subsonic flight regimes, the propulsion systems of major interest are turboshaft and turboprop engines, in sizes of less than 20 lb/sec airflow, with associated drive trains, reduction gearing, propellers, and other thrust producers. Tri-service agreements have established the Army's responsibility for conducting R&D in this area.

The general objectives of propulsion system R&D are to provide the technology for turboprop and turboshaft engines of less than 20 lb/sec airflow and for the associated drive trains, reduction gearing, propellers, and other thrust producers which are:

- More efficient
- Lower weight
- More reliable
- More maintainable
- Lower in cost than those currently available
- Less vulnerable

The R&D activities that result in continued improvement in the characteristics of propulsion systems can be separated into subdisciplines. The principal ones are defined in table PR–A. In addition to these subdisciplines, advanced development effort is conducted in the overall areas of engines and drive trains. The objective is to demonstrate that advances in propulsion and drive train component technology are translatable into improvements of actual aircraft engines and drive trains. These advanced development efforts are discussed in the Laboratory Project subsection of this section.

Program objectives and quantified achievement goals for each subdiscipline are presented in charts PR–I through PR–V located in the appropriate subsections. Incremental achievement goals are shown for the 20-year span covered by the Plan with application on near-term, mid-term, and future airmobile systems.

TECHNOLOGICAL DISCUSSION

GENERAL

The requirements, characteristics, interrelationships, and rationale for Army aircraft propulsion system technology are presented in this subsection

TABLE PR–A
PROPULSION SUBDISCIPLINE DESCRIPTION

AEROTHERMODYNAMIC COMPONENTS	• Covers the broad subjects of predicting and demonstrating improved performance of inlet protection systems, compressors, combustors, turbines, and exhaust systems. The primary objectives are reduction in complexity plus improved efficiency and reliability.
CONTROLS & ACCESSORIES	• This area includes controls, fuel pumps and metering systems, oil pumps, starters, alternators, and sensors. The primary objectives are reductions in weight, volume and cost plus improved reliability.
MECHANICAL ELEMENTS	• Included in this area are bearings, seals, gears, shafting, couplings, clutches, and casings. The development of lighter, less vulnerable, and more reliable elements is a continuing objective.
THRUST PRODUCERS	• Covers those elements involved in converting the mechanical energy produced by the engine into thrust for the aircraft, primarily propellers and fans. Primary objectives are improved efficiency and reliability plus lower weight.
MATERIALS PROCESSING & APPLICATION	• Covers the application of new alloys or materials possessing improved thermal and mechanical properties and the development and control of the processes employed to produce the material and fabricate parts. Objectives are improvement of system efficiency through increased temperature capability, improved reliability, and reduced manufacturing costs.

together with a discussion of technological thrust areas.

Small size and an unusual operating environment impose special requirements on Army aircraft propulsion systems. Advances in technology that have been successfully demonstrated in large, modern turbofan and turbojet engines cannot be directly scaled to the less than 20 lb/sec size, which the Army requires. Innovative technology is required in a number of areas. For example: scaling of multi-stage axial compressors would result in blading which is prohibitively small from the standpoint of manufacturing tolerances and durability; therefore centrifugal compressor stages are usually used. Similar difficulties are encountered with other propulsion system components. In addition, helicopter transmissions and drive trains are unique. No other vehicle imposes similar input and output speed and torque requirements or similar load carrying requirements.

The operating environment imposes a significant demand for innovation. Helicopter propulsion systems are subjected to frequent starts and shutdowns as well as frequent power changes. The system is also subjected to severe and continuous vibration. Operation of aircraft from unimproved areas results in exposure of the propulsion system to large quantities of sand and dust. Low altitude operation exposes the propulsion system to small arms as well as anti-aircraft weapons. Innovative technology is required not only to achieve acceptable levels of performance in Army aircraft propulsion systems but to enable them to survive in the Army environment as well.

Figure PR–1 illustrates the relationship between specific power (proportional to engine size and weight per horsepower), specific fuel consumption (SFC), and the cycle parameters of pressure ratio and turbine inlet temperature for a family of potential gas turbine engine design points. The figure shows that significant improvements in engine performance can be obtained through increases in pressure ratio and temperature. However, without advances in technology, these improvements can only be obtained at the

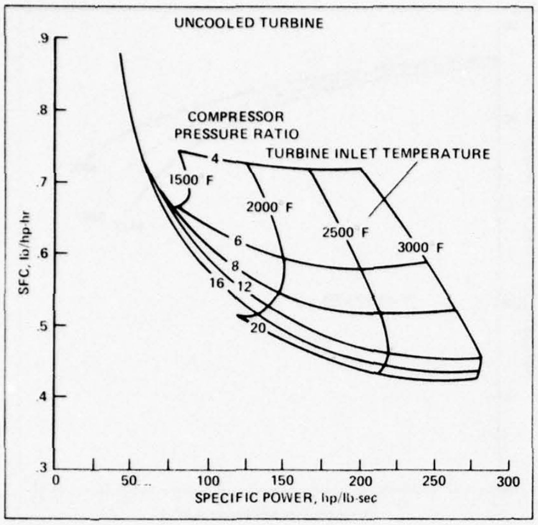


Figure PR–1. Design point performance – SLS.

expense of increased complexity, increased cost, stronger IR signature, added reliability problems, and increased sensitivity to sand and dust.

The data shown in figure PR–1 represent design point performance. Because Army aircraft operate most of the time at part power, careful attention should be given to off-design performance. Figure PR–2 illustrates part-power performance of two engine cycles. The figure shows that although engine A has slightly better fuel consumption at 100 percent power, engine B has a significant advantage at part power. Selection of cycle parameters should be made only after analysis of the anticipated duty cycle of the engine.

The Army requirement for small size engines leads to unique problems, the solution to which requires innovative technology. Successful refinement and attainment of efficient performance in modern turbofan and turbojet engines in the 200 lb/sec size range cannot be directly scaled down to the less than 20 lb/sec size. For example: centrifugal compressors are often substituted for several very small axial stages; radial flow turbines are often used, rather than small axial turbines; combustors demand special attention to both the configuration and the fuel injection process; and controls must be more rugged, smaller, and less complicated. All engine components must be developed to improve functional performance, using less costly configurations having fewer elements.

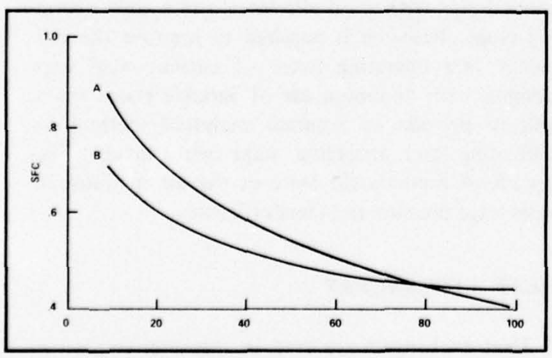


Figure PR–2. Off-design performance.

The development of a serviceable engine embodying advanced technology involves steps subsequent to the development of improved components. A gas generator consisting of a compressor, combustor, and turbine may be assembled and run to demonstrate gas performance and a solution to matching problems. The STAGG (Small Turbine Advanced Gas Generator) program illustrates this phase. Further progress toward a serviceable engine may be made through a demonstrator engine program, in which the desired engine type (turboshaft, turboprop, or turbofan) is built to prove the level of output performance available for a production engine. Recent applications of this technique are the 1500 hp demonstrator engine, which led to the T700 engine for the UTTAS and AAH and the new 800 hp Advanced Technology Demonstrator Engine (ATDE).

AEROTHERMODYNAMIC COMPONENTS

INLET PROTECTION

Improved resistance to erosion by sand and dust has been accomplished by the use of particle separators ahead of the compressor, frequently integral with the engine. The operating time prior to destructive erosion tends to be the reciprocal of the fraction of particles left in the inlet air after separation, and a tenfold increase in operating time now appears possible. This separation is accomplished at the expense of approximately 1 percent of the engine power, caused by the pressure loss in the separator. Research is directed toward improving separator effectiveness while reducing the pressure drop and power loss, and decreasing the separator size and scavenge flow required. The basic resistance of the engine, principally the compressor, to sand and dust erosion can be

improved by using erosion resistant materials, and by the application of coatings more resistant than the base metal. Research in both materials and coatings will provide greater engine life in the sand and dust environment.

An integrated inlet protection system has been developed as part of the T700 engine program. During the course of the engineering development program, a problem was encountered with scavenge system durability. As a result, an exploratory development effort was conducted that has demonstrated scavenge systems with significantly improved durability. The most important current activity in this subdiscipline is the development of integral inlet protection systems as part of the two 800 hp ATDE contracts. Planned future work includes continuing materials and coatings research for erosion resistance and initiation of an exploratory development effort to investigate advanced separator system concepts.

COMPRESSORS

Centrifugal Compressor–Single Stage. The attainment of high pressure ratios in one centrifugal compressor stage, that replaces several axial stages, promises major improvements in simplicity, cost, and ruggedness of the small engine. At present, the efficiency of the centrifugal stage (and in some cases its surge-free operating range) is less than desired. The improvement of these deficient characteristics requires research into the nature of the flow field in the impeller inducer, the impeller, the vaneless discharge passage, and the diffuser. Location and definition of the losses and the factors causing surge will assist in the development of compressors having reduced losses and a wider operating range. It is essential that research in this area be coupled with the derivation and use of analytical methods covering three-dimensional flow phenomena in curved passages. Figure PR–3 presents a trend in centrifugal compressor pressure ratio and efficiency.

Centrifugal Compressor–Combined Stages. The use of a centrifugal compressor stage together with other compressor stages is typical in Army turboshaft and turbojet engines. The compressor of many small engines consists of one or more axial stages followed by a single centrifugal stage. Some engines use two centrifugal stages in series. The problems of single-stage design are thus complicated by the problem of matching, and of predicting the operating range, pressure ratio, and efficiency of the stage or the combined stages. Research is required for the development, correlation, and refinement of analytical methods suitable for the prediction of the characteristics of combined stages. Further research is required to determine the optimum division of work between the individual elements in the combined compressor assembly.

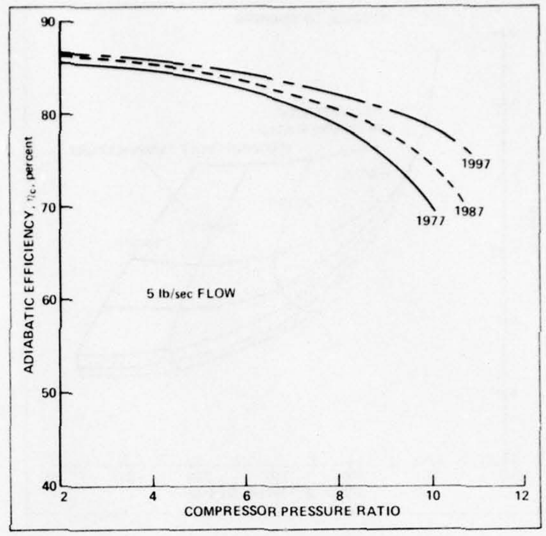


Figure PR–3. Centrifugal compressor trends (design point performance).

Axial Compressor. Multistage axial compressors are commonly used in conventional large turbofan and turbojet engines. Small engines use the axial-plus-centrifugal configuration to avoid impractically small parts (such as blades), and to obtain improved ruggedness, reduced cost, and increased resistance to sand and dust. The type of axial stage best suited to the small engine is characteristically a high flow, transonic design with good efficiency and a wide operating range. Research is required to improve the efficiency and operating range of current axial stage designs, with minimum use of variable stator vanes, and to provide an accurate analytical method for predicting and analyzing stage performance. Figure PR–4 presents the state of the art in transonic axial stage pressure ratio and efficiency.

HEAT EXCHANGERS

Heat exchangers are used in regenerative gas turbines to transfer waste heat from the engine exhaust to the air entering the combustor. This reduces the

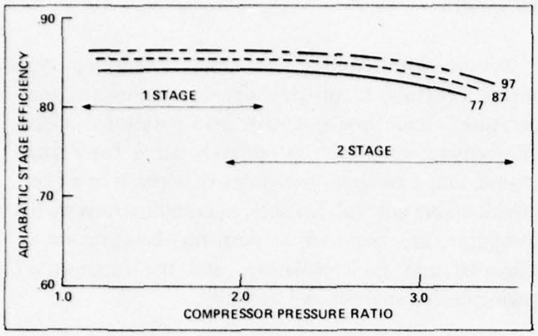


Figure PR–4. Transonic axial compressor trends (design point performance).

amount of fuel required in the combustor. The reduction in fuel consumption is substantial, especially at reduced power settings. Previous studies have shown that the weight and cost penalties associated with these heat exchangers outweigh their fuel savings in aviation applications. Improved technology, especially in materials and fabrication processes, plus the increasing cost and less certain availability of fuel may change this conclusion. There is a study under way that will determine the weight, cost, fuel, and IR signature trade-offs between regenerative and nonregenerative engines. This study will identify the most promising candidates for further R&D efforts.

COMBUSTORS

Small gas turbine combustors normally require many hours of testing to progress from conceptual design to production hardware. Though generalized design rules apply, refining the performance inevitably becomes a "cut-and-try" procedure. Additional research is required to achieve predictability of such little understood processes as fuel atomization, three-dimensional turbulent mixing, chemical kinetics, and pattern factor control. Because the fuel availability outlook is continually changing, new concepts must also be explored to accommodate a wider tolerance of fuels and fuel blends. Research is also needed to develop improved high temperature liner materials, possibly nonmetallic ones, that will require less cooling.

Specific areas of projected future effort in combustor R&D include:

- Primary zone radiant heat reduction
- Improved fuel atomization
- Experimental investigation of very small combustors
- Alternative fuel combustor design
- Combustor discharge temperature pattern factor improvement

TURBINES

Axial Turbines. The use of axial turbines in small engines has been complicated by factors not subject to scaling, such as tip clearance, minimum wall thickness in hollow blading, and cooling. Research is required in these areas, as well as in the development of improved methods for calculating and correlating thermal gradients and thermal stress effects plus mechanical stress and stress concentrations while relating these factors to actual hardware and to subsequent engine operational experience. Advances are needed in the prediction of high cycle fatigue, low cycle fatigue, stress rupture, high temperature creep as well as the correlation of material property data, mechanical test data, and engine hardware experience. Research is needed to advance superalloy fabrication and materials technology toward the production of reliable, lower-cost components suitable for more severe engine environments.

The use of single-stage, high-work, cooled, axial turbines has been limited by their low performance compared to that of multi-stage axial turbines. Research is needed to improve the aerodynamic efficiency of small, cooled, high-work, axial turbine stages.

Radial Turbines. The use of radial turbines in small engines is expected to increase, particularly in combination with radial compressors. Advantages include a reduction in the number of mechanical elements and in cost. Research is required to develop predictive techniques for metal temperature and heat transfer, and for stress analysis. The use of radial turbines at high temperatures requires research in the configuration and effectiveness of cooling arrangements, together with investigation into the materials and fabrication problems created by the high temperature and cooling. Research should address the problems of high specific output and the cooling of small rotors. Trends in turbine efficiency and inlet temperatures are predicted in figure PR–5.

AEROTHERMODYNAMICS TOPICS SUMMARY

The various research topics discussed under aerothermodynamics can be categorized as shown in the

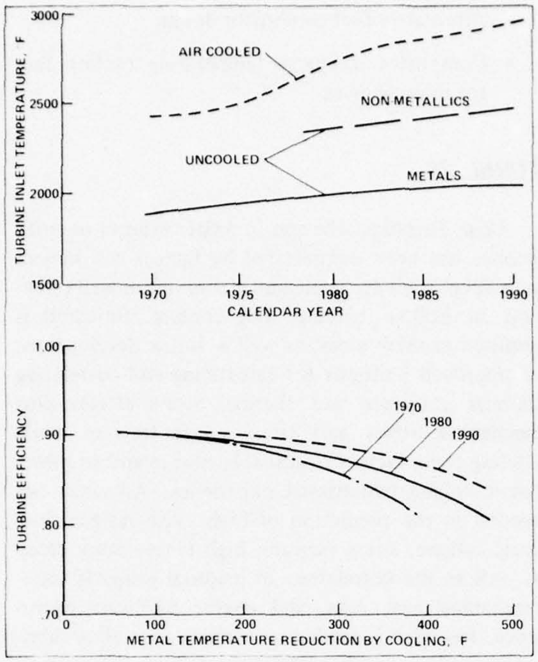


Figure PR–5. Turbine inlet temperature.

listing in chart PR–I. Quantified achievement goals are also indicated in the chart.

CONTROLS AND ACCESSORIES

FUEL CONTROL

Fuel controls for small gas turbines have been relatively heavy, costly, and limited in function. Research is required to provide improved function, such as closed-loop surge protection rather than scheduling, engine health sensing and display, and direct sensing and display of compressor-turbine inlet temperature. New technology in electronics, fluidics, pyrometry, pressure transducers, and computers must be explored and applied.

FUEL PUMPS

Fuel pumps require functional improvement. Fuel pumps currently are limited in their capacity to pump a mixture of vapor and liquid, and must be supplied with fuel under pressure by boost pumps. Research is required to improve the vapor tolerance, provide a suction capacity that eliminates the boost pump, and reduce the size by increasing the rotational speed toward gas generator shaft speed.

SENSORS

Sensors are required for new, closed-loop type engine controls, to provide signals of pressure, temperature, fluid flow quantity, and rotational speed. The sensors must be appropriately sized for a small engine, and have response times that result in a functional, stable control. Sensors, in combinations with a computer, are required to perform the function of diagnosis and fault isolation, and the function of engine health analysis and display.

CONTROLS AND ACCESSORIES TOPICS SUMMARY

The various research topics discussed under controls and accessories can be categorized as shown in the listing in chart PR–II. Quantified achievement goals are also indicated in the chart.

MECHANICAL ELEMENTS

BEARINGS

Bearings employed in gas turbine engines and helicopter transmissions fall into three broad categories: (1) lightly loaded, high-speed engine main-shaft bearings, (2) moderately to heavily loaded accessory drive bearings, and (3) heavily loaded main reduction gear bearings. In the second and third categories, the bearings of the input pinions are also critical in speed because they operate at gas generator and power turbine speeds, respectively.

Continued research has resulted in state-of-the-art rolling contact bearings of vacuum induction melt-vacuum arc remelt (VIM-VAR) M-50 steel with DN values of about 2×10^6. In addition, engine shaft bearings and accessory drive bearings that require no oiling have been demonstrated in the form of gas lubricated bearings, and further research has promise of eliminating the gas turbine lubrication system. Foil-type air bearings and hybrid bearings are candidates with similar potential.

Present areas of research in rolling contact bearings for helicopter transmission input pinions are:

- Roller bearings with thrust carrying capability of VIM-VAR M50
- Tapered roller bearings with VASCO X2 inner race

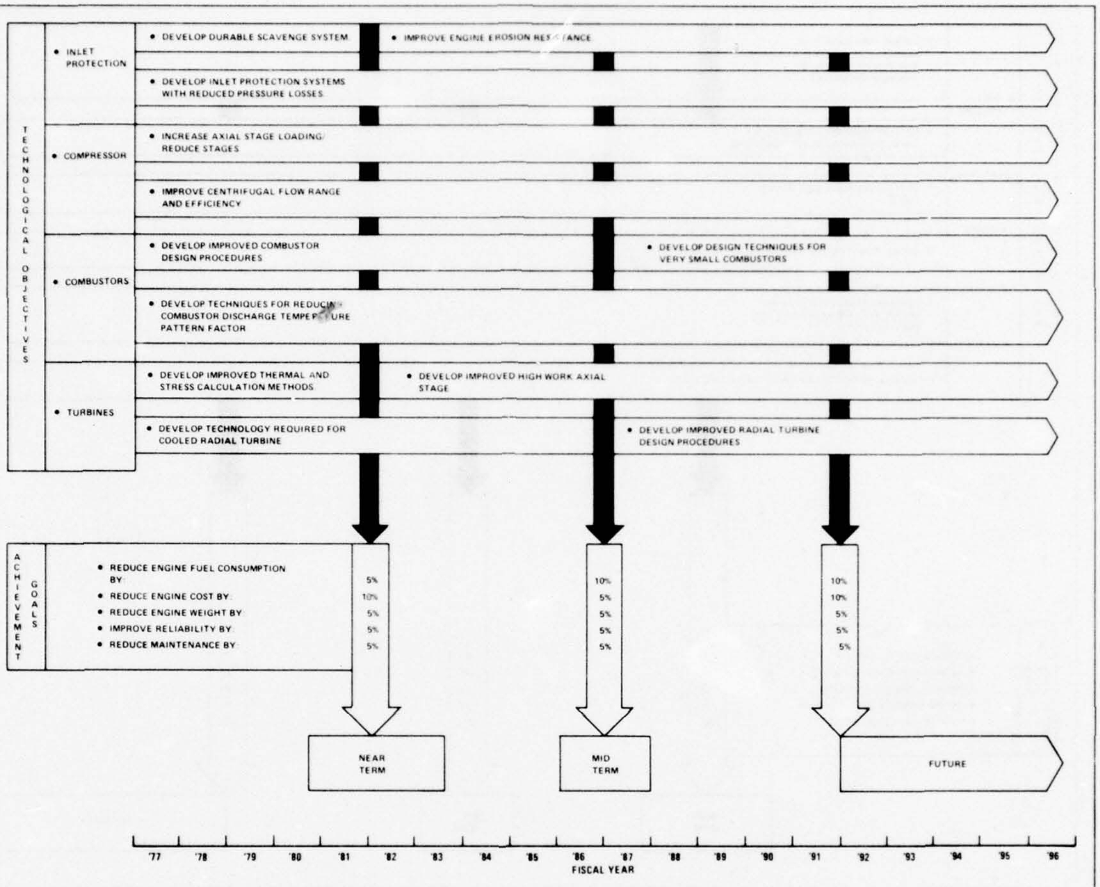


Chart PR–I. Summary of Aerothermodynamics Objectives and Achievement Goals.

- Tandem ball bearings with carpenter X-53 inner race
- Ball bearings with VASCO X2 inner race

The last three bearings have inner races of high hot hardness gear steels for an integral shaft/inner-race application. Also under development are ceramic (silicon nitride) bearings for all applications.

Research needed to provide improved bearings are:

- Impact strength to survive a ballistic hit
- Fracture toughness to prevent catastrophic failures emanating from surface fatigue
- High-temperature lubricants with excellent load carrying capability
- Method of rating main rotor bearings other than DN values (which do not consider centrifugal effects)
- Skewing of rollers
- Design technology for small engine rotor bearings in the 2×10^6 to 3×10^6 DN range

GEARS

For more than three decades, aircraft gears have been manufactured of AISI type 9310 steel with case carburized teeth which are finish ground. The ductile core has excellent bending fatigue life, impact strength, and fracture toughness; the hard surface has excellent surface fatigue life, and the high surface finish with lubrication inhibits scoring. Face widths are established by contact compressive stress (Hertzian) consistent with design life; diametral pitch is selected and tooth thicknesses approtioned for acceptable bending stress. The latter stress is always

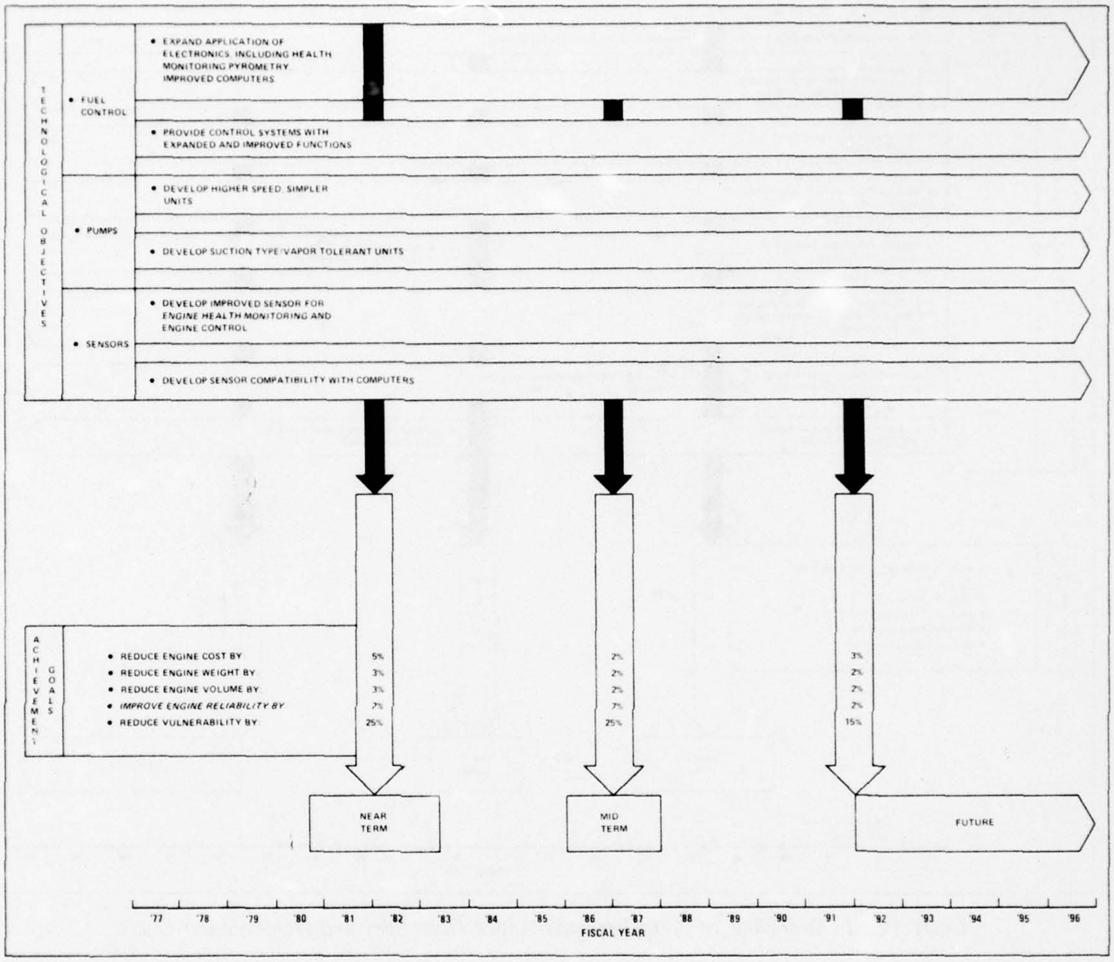


Chart PR–II. Summary of Controls and Accessories Objectives and Achievement Goals.

conservative so that the failure mode is pitting; pitting is not catastrophic and can be detected by an increase in noise and vibration.

On-going research programs to further the state of the art in gearing are:

- New gear steels with high hot hardness for survivability after loss of lubricant
- High-contact-ratio spur gears with buttressed teeth and double-helical gears in epicyclic systems, for a reduction in weight and noise, and for an increase in life and efficiency.

Areas of research needed to provide improved gearing are:

- New gear materials having higher allowable unit loadings than present materials.
- Investigation of the basic mechanism of scoring including the behavior of the lubricant film and surface treatment.
- Investigation of tooth forms with greater bending strength and lower contact stresses.
- Improved lubricants capable of operation at higher temperatures.

SEALS

Seals are employed in gas turbine engines to prevent/minimize air leakage and oil leakage. These

seals are of two types: non-rubbing (e.g., labyrinth seals) and rubbing contact seals. They operate at ever increasing speeds, temperatures, and pressure differentials. Helicopter transmission oil seal applications must contend with speed and temperature.

Present areas of research in the field of seals are:

- Magnetic seal at transmission input for constant pressure on the runner
- Radial carbon seal at transmission input
- Liftoff face seal at turbine inlet for thrust balancing
- Rotating runners (at half speed) for reduced rubbing velocity

Areas of research needed to provide improved seals are:

- Increased running speeds for both contact and non-contact seals
- Increased pressure differential capability
- Improved transient rubbing tolerance
- Increased life capability for very low leakage seals

CLUTCHES

Provision for engine failure or fuel runout has been made in helicopters by driving the rotor system through an overrunning clutch, thus eliminating the torque drag of a dead engine and avoiding a major performance loss during partial-engine or autorotating flight. Usually, overrunning clutches have been designed to operate at speeds of 2000 to 6000 rpm; they are located at the first, or between the first and second, gear reduction stages in order to eliminate high speed problems. This has resulted in heavy, massive designs. From the standpoint of weight and size, it is desirable to locate the overrunning clutch at the high speed engine output. Clutches suitable for operation at gas turbine shaft speeds have been developed.

Three clutch concepts, a sprag, a ramp-roller, and a new-concept spring clutch were designed and tested under simulated UTTAS operational conditions (20,000 rpm). Operation of all three clutches was generally satisfactory and an overrunning clutch design guide has been published. Improved technology should be developed to correct minor deficiencies in these concepts and research is required to investigate other new clutch concepts. Research should be pursued to provide increased speed capability (greater than 30,000 rpm) for application to future systems compatible with advanced technology engines in the 800 shp and lower category.

DRIVE TRAIN STRUCTURE AND ACCESSORIES

A large fraction of the drive train weight consists of housing structure, accessory drives, mounting structure, lubrication system, rotor brake, and related elements auxiliary to the main gear train. Substantial potentialities for weight and cost reduction lie in these areas and further investigation is required.

Present areas of research are:

- Transmission housings of corrosion-resistant steel weldments for lightweight and low cost, and ones that have the potential for eliminating the oil cooler
- Transmission housing of polyimide graphite composite for reduction in weight and cost
- Transmission mini-lube system whereby oil flow and quantity are reduced to 20 percent of current requirements

Areas of research needed to provide improved drive train structure and accessories are:

- High-temperature lubricants
- Vibration absorbing mounts for the transmission/rotor system
- Increased coupling speed capability (up to 30,000 rpm)
- Couplings capable of misalignments of up to 6°
- Reduced external heat rejection (eliminate oil cooler)
- Increased speed capability for accessories and accessory drives
- Increased rotor brake energy storage capability (wet rotor brake)

TECHNOLOGY TRENDS

Trends in gear loading, bearing loading, and transmission weight fraction are presented in figure PR–6.

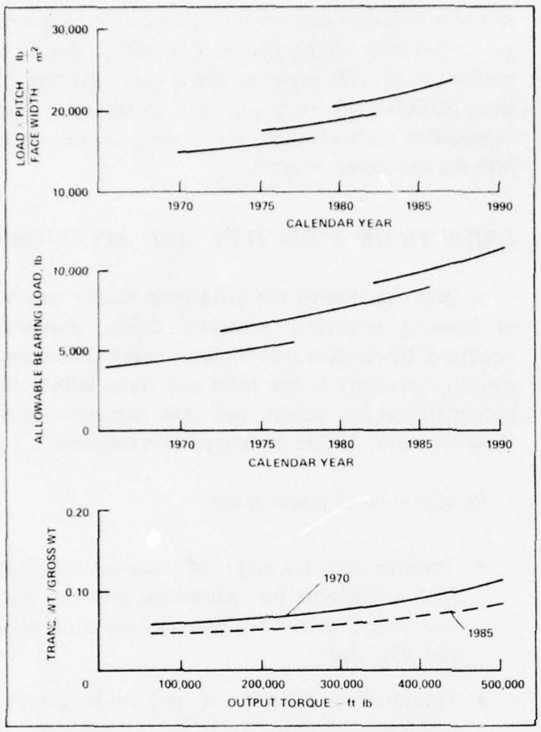


Figure PR–6. Technology trends – mechanical elements.

MECHANICAL ELEMENTS TOPICS SUMMARY

The various research topics discussed under mechanical elements can be categorized as shown in the listing in chart PR–III. Quantified achievement goals are also indicated in the chart.

THRUST PRODUCERS

GENERAL

The term "thrust producer" categorizes the device with which the power developed by the gas generator is converted into thrust. The gas generator is presumed to deliver shaft power by the addition of a power turbine.

PROPELLER AND PROPELLER REDUCTION GEAR BOX

Propellers, with their associated accessories and governing systems, have assumed a variety of configurations: constant-speed, feathering, reversing, and acceleration-sensitive-governing; aluminum, steel, and fiberglass blades; fluid and thermal deiced. Advances in propeller technology have been paced by propeller use, which now is confined to a small and shrinking fraction of the military fleet, with a consequent diminished level of activity and progress.

Research on propellers is required to provide lighter, simpler, and more reliable configurations. The application of elastomeric bearings to blade retention is one example; governing by solid-state electronics with a self-contained power source is another. Manufacturing processing and design must be developed to provide a blade with the low weight of the composite blade at a cost comparable to the aluminum blade. The use of cyclic pitch for control and stability must be investigated.

Propeller reduction gears are technologically similar to helicopter transmission gears, and the research areas previously described are applicable to them. An additional aspect of the reduction gear requiring review and careful analysis is the interface between the propeller and the gearbox, where the integral gearbox-propeller design has promise of reduced weight and reduced complexity.

FAN

The use of a fan to convert shaft energy into thrust is common in large engines. Such an arrangement is flexible, since the flow and pressure ratio of the fan may be selected to match a vehicle requirement, and the fan is normally used to supercharge the gas generator and increase its ability to generate available energy. Thus, a gas generator with a 3000 hp rating as a separate unit may actually drive a 4000 hp fan simply by increasing fuel flow to match the increased inlet density.

The flexibility of the fan-gas-generator is unique. It can be used as a conventional direct drive fan engine to provide thrust at high speed; a source of warm pressurized air for a rotor reaction drive; a high bypass fan, with reduction gearing, to supply thrust at low speed; a convertible fan-shaft-power engine to provide either shaft power or thrust; or a thrust source, with variable pitch, suitable for a fan-in-fin or fan-in-fuselage antitorque system.

Research on fan components is required to provide:

- Improved prediction techniques for blade natural frequencies and stresses.

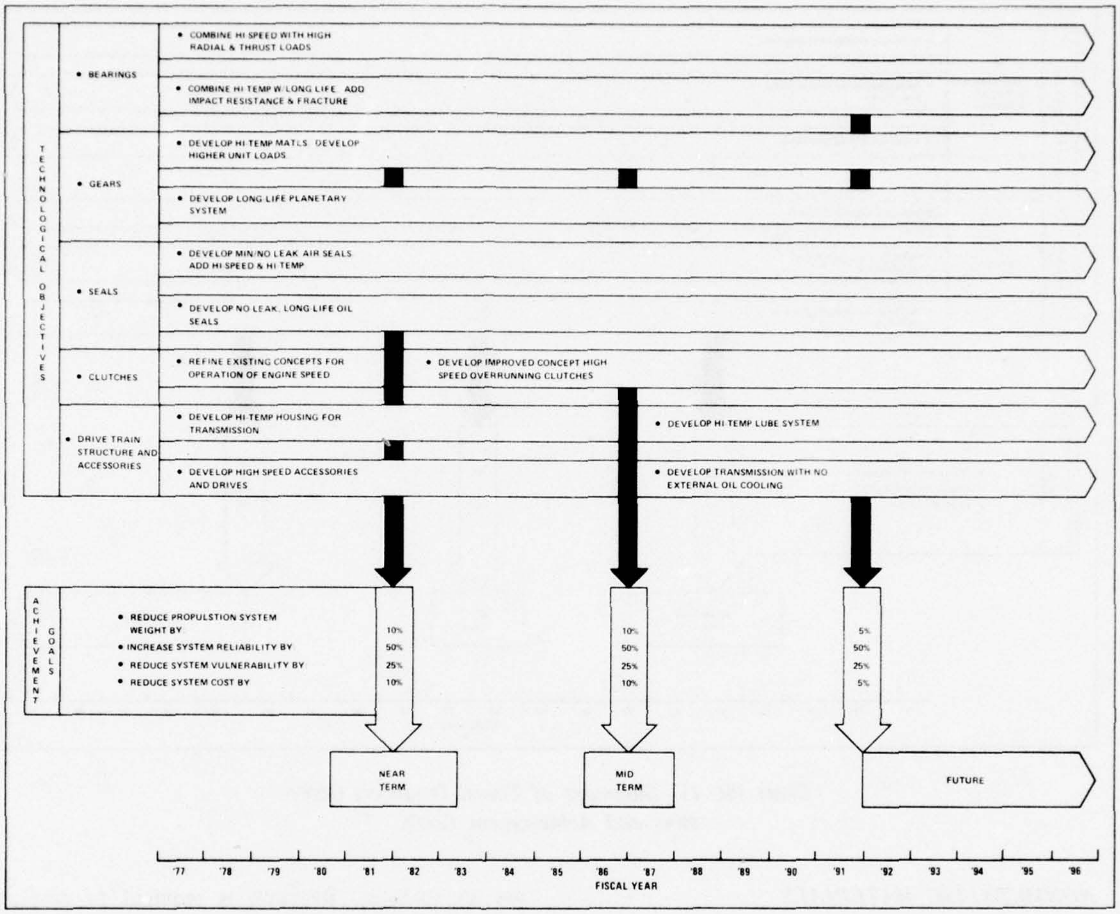


Chart PR–III. Summary of Mechanical Elements Objectives and Achievement Goals.

- Variable pitch mechanisms, materials, and processes possessing satisfactory resistance to sand and dust erosion.
- Materials and manufacturing methods resulting in blades of lower weight and increased durability.

THRUST PRODUCERS TOPICS SUMMARY

The various research topics discussed under thrust producers can be categorized as shown in the listing in chart PR–IV. Quantified achievement goals are also indicated in the chart.

MATERIALS, PROCESSING, AND APPLICATION

METALS AND ALLOYS

Refractory metals (niobium, molybdenum, tantalum, tungsten, osmium, iridium) have had promise of improved strength at high temperature, for use in turbine blades, but in the pure form have been inappropriate because of low ductility and poor resistance to oxidation. Research is required to develop alloys of these basic metals to correct their brittleness and susceptibility to oxidation, and to develop self-healing, high-temperature-resistant coatings.

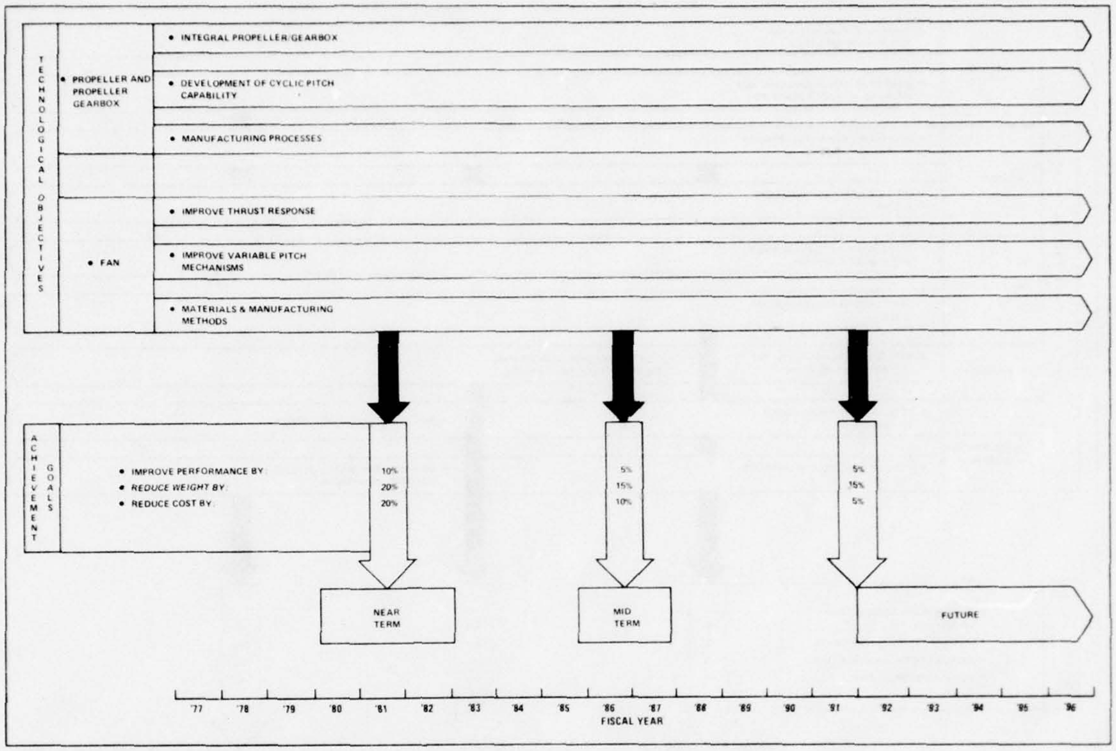


Chart PR–IV. Summary of Thrust Producers Objectives and Achievement Goals.

NONMETALLIC MATERIALS

Silicon nitride and silicon carbide have properties that provide potential for higher temperature operating capability, lower component costs, and lighter weight. Further research is required to improve ductility, possibly by alloying or by the use of a tough matrix, before the ceramic material becomes practical.

Ceramic materials, such as the oxides of aluminum, magnesium, titanium, and zirconium, have properties suggesting their use as a high-temperature structure, but research is required to increase their ductility while maintaining high strength to apply them to severe usage such as a turbine blade. The use of ceramics for high-performance heat exchangers, particularly the periodic type, requires research that will improve the specific heat and the thermal conductivity of the material. Additionally, the high strength silicon nitride and silicon carbide ceramics considered suitable for turbine use have lower thermal expansivity values than the metals currently in use in turbines. Research is required to develop methods of mounting or joining ceramics to metallics.

Composite materials are also being considered for application to parts of the static structure of propulsion systems, both engines and drive trains. Development of new design procedures are needed to take advantage of the properties of these materials.

Research is also required to develop new and/or improved means of non-destructive inspection for both ceramic and composite parts.

COATINGS

Protective coatings allow the use of some high-temperature alloys in applications otherwise barred by poor resistance to oxidation or sulphidation. Research on improved coatings is required to provide protection at higher temperatures for both outer and inner surfaces of turbine blades and disks. Research on erosion and corrosion resistant coatings for the cool section of the engine is also required.

CASTING

The fabrication of air-cooled turbine vanes, blades, and wheel-and-blade assemblies is normally accomplished by casting. In addition, certain complex engine housings and transmission housings are cast. Research is required to improve the capability of casting complex internal passages, and improving the material properties of the cast pieces, while increasing the foundry recovery and reducing the cost of the parts.

FORGING

Application of isothermal forging to a number of superalloys has been successfully demonstrated. This process can generally be executed on much smaller, lighter, and less costly equipment than that used for conventional impact forging. Research to define the range of applicability of the process and development of applications to propulsion systems is required.

INTEGRAL ASSEMBLY FABRICATION

The problem of fabricating integral wheel-and-blade assemblies, and complex shapes of radial compressor impellers, has resulted in attempts to use several methods of manufacturing that avoid the expensive "machined-all-over" method. Promising processes include bi-casting, powder-forming and sintering, and plastic extrusion. Research on these fabrication techniques and associated non-destructive inspection procedures must be conducted to achieve lower costs.

MATERIALS, PROCESSING, AND APPLICATION TOPICS SUMMARY

The various research topics discussed under materials, processing, and application can be categorized as shown in the listing in chart PR–V. Quantified achievement goals are also indicated in the chart.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the propulsion discipline. The OPR is not an objective of the Plan, but is provided to show the procedure used in this selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the propulsion discipline can be established from the near-term quantified achievement goals listed in charts PR–I through PR–V. Specifically, the near-term objectives are:

- Demonstrate improved engine technology compared to current production engines in the 800 shp class as follows:
  - Reduce fuel consumption by 20–25 percent
  - Increase specific power by 40–60 percent
  - Reduce vulnerable area by 40–50 percent
- Develop improved drive train technology that will:
  - Reduce weight by 20 percent
  - Increase MTBR by 100 percent
  - Reduce production cost by 20 percent
  - Improve survivability and reduce vulnerability
- Reduce propulsion system costs
- Demonstrate engine components utilizing advanced system components
- Establish requirements for system design and development

PROGRAM PRIORITIES

General. Table PR–B presents, in a prioritized listing, the propulsion technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts that support the near-term technical objectives.

Technology Subdisciplines. The propulsion technology subdisciplines are represented by the following major topical areas:

- *Aerothermodynamic Components.* This area covers the broad subjects of predicting and

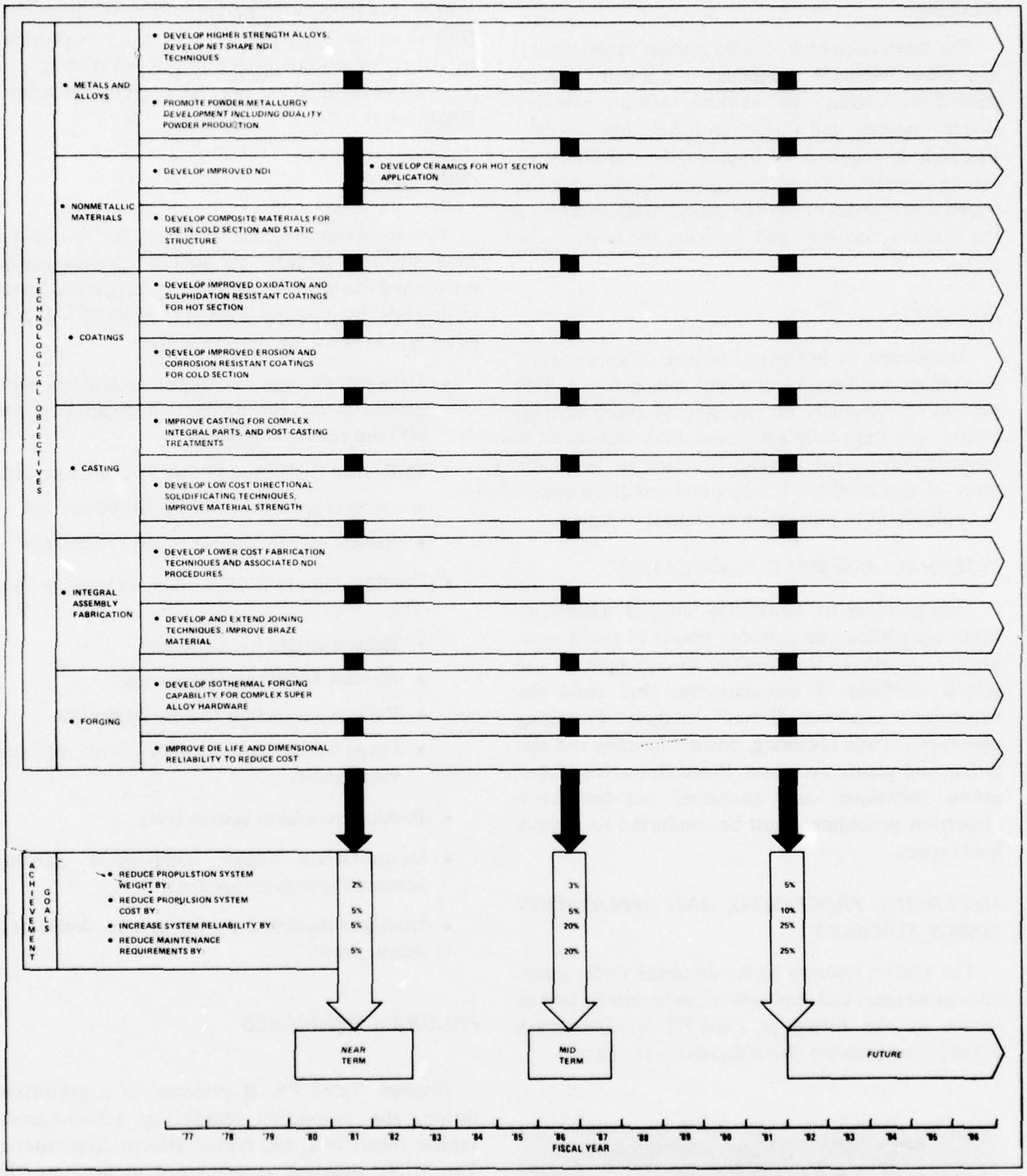


Chart PR–V. Summary of Materials, Processing and Application Objectives and Achievement Goals.

improving the performance of compressors, combustors, turbines, inlet systems, and exhaust systems, thus leading to higher pressure ratio per stage and reduced specific fuel consumption.

- *Controls and Accessories.* This area includes fuel nozzles, fuel pumps, fuel scheduling, and fuel metering, with emphasis on development of more accurate and compact accomplishment of all required functions.

TABLE PR–B
PRIORITIZED PROPULSION OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Aerothermodynamic components	I	• Power transmission	I	• Performance	I
• Controls and accessories	II	• Gas generators/ power turbines	II	• POL requirement	II
• Mechanical elements	III	• Inlet/exhaust systems	III	• Cost	III
• Materials processing and application	IV	• Drive shafting	IV	• Safety	IV
• Thrust producers	V			• Vulnerability	V
				• RAM	VI

- *Mechanical Elements.* All power transmission components are included in this area; such as bearings, gears, cases, shafting, clutches, brakes, and seals, etc. The development of lighter and more reliable elements is a continuing R&D goal.
- *Thrust Producers.* This area covers the elements involved in converting shaft horsepower into propulsive effort, and includes propellers, fans, and associated components.
- *Materials Processing and Application.* This topic is concerned with the development of improved high-temperature materials and advanced fabrication methods for these materials.

Vehicle Subsystems. Vehicle subsystems, as related to propulsion technology are categorized as follows:

- Power transmission
- Gas generators
- Inlet/exhaust systems
- Power turbines
- Drive shafting

System Effectiveness. System effectiveness refers to the characteristics of the vehicle of which the propulsion system is an integral part. The description of these elements is as follows:

- *Performance.* Encompasses speed, endurance, range, and ability to operate in an adverse environment.
- *POL Requirements.* Covers the logistics of maintaining operations when located at a remote site and is also included as a major element of operating costs.
- *Cost.* Covers acquisition, operating, and total life cycle costs.
- *RAM.* Primarily, RAM is the freedom from scheduled and unscheduled maintenance or repair but, where necessary, easily maintainable.
- *Vulnerability.* The susceptibility of the system to battle damage that results either in failure to perform a mission, long-time inactivation for repairs, or loss of vehicle.
- *Safety.* Encompasses the entire safety and survivability field with emphasis on propulsion caused problems; that is, engine stoppage, fires, etc.

Priorities. With reference to table PR–B, the propulsion subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the propulsion R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 propulsion technology development program.

The major technical thrusts for propulsion R&D are as follows:

- Reduce fuel consumption
- Improve heat transfer technology to reduce engine size, weight, and fuel consumption.
- Reduce IR signature and vulnerable area.
- Reduce propulsion system life cycle costs and reduce vulnerability to engine foreign object damage.

The major thrust of the propulsion R&D effort is to improve V/STOL aircraft engines and drive trains by reducing their size, weight, vulnerable area, cost, and fuel consumption while improving reliability, maintainability, and survivability. Reducing the size, weight, and cost of engines and drive trains is important for the attainment of overall system objectives. It allows more power to be installed in an aircraft; more power improves maneuverability, engine-out performance, and overall mission performance. It also compensates for the performance, cost, and empty weight penalties associated with improving IR signature, reliability, maintainability, survivability, vulnerability, and crashworthiness.

The application of aerothermodynamic technology to the improvement of heat transfer components has a powerful leverage in the improvement of the output and efficiency of gas turbine engines and thus, vehicle performance and POL requirements. Substantial improvements in fleet effectiveness and in specific vehicle capability will follow from this thrust.

The reduction of propulsion system costs is the result to be expected from a better knowledge of costing factors, research leading to improved manufacturing capabilities, and from the attenuation of foreign object damage provided by efficient particle separators.

LABORATORY PROJECTS FOR FY78 IN PROPULSION

INTRODUCTION

Technological activities in propulsion and drive trains include basic work on internal flow and the behavior of mechanical devices, as a 6.1 effort; the development and test of components of power devices and of drive trains, as a 6.2 effort; and demonstration of successful components of propulsion and drive trains in assemblies, including rig testing and flight testing, as a 6.3 effort. All 6.1 activities and some 6.2 activities are conducted by the Propulsion Laboratory colocated with the Lewis Research Center of NASA. Many 6.2 activities and all 6.3 activities are conducted by the Applied Technology Laboratory, Fort Eustis, Virginia.

DESCRIPTION OF PROJECTS

Research in Propulsion. Project 1L161102AH45-TA II consists of basic research, conducted jointly with NASA, aimed at advancing the technology of propulsion and drive trains. The work is directed toward the solving of special problems involved in the development of small gas turbines, and the investigation of advanced concepts in mechanical devices used in drive trains.

Propulsion Technology. Project 1L262209AH76-TA III is an exploratory development effort providing the technology necessary to advance the development of propulsion systems and of drive trains that are more effective than existing systems. This work is accomplished by developing components that are more efficient, weigh less, are smaller, cost less, or are more serviceable. Investigations have been divided into two work areas. Work area I covers engine components and work area II covers other propulsion components. Activities normally encompass analysis, design, fabrication and test of components such as inlet separators, compressors, combustors, turbines, accessories, transmissions, gears, clutches, couplings, bearings, and thrust producers.

Demonstrator Engines. Project 1L263201D447 provides validated technology for small engines. Advanced component technology from funded (6.2) programs, and from industry-sponsored IR&D programs will be incorporated into advanced gas generators and/or experimental engines for test or demonstration.

Propulsion Components. Project 1L263201DB72 provides validated technology for advanced transmission systems and thrust producer concepts. Advanced component technology from exploratory development (6.2) programs and from IR&D programs is used to design, fabricate, and test advanced drive train and thrust producer concepts.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the propulsion R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.1, 6.2, and 6.3 propulsion R&D efforts are shown in table PR–C. Included in the table is the ratio of the propulsion efforts to the total 6.1, 6.2, and 6.3 R&D efforts of the Research and Technology Laboratories.

TABLE PR–C
PROPULSION TECHNOLOGY FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78	
6.1	1L161102AH45-TA II	1148	23%
6.2	1L262209AH76-TA III	2680	18%*
6.3	1L263201D447	2905	35%
	1L263201DB72	215	3%

*Does not include Project 1L262201DH96 Aircraft Weapons Technology funds.

INTRODUCTION

TECHNOLOGICAL DISCUSSION

DIAGNOSTIC TECHNOLOGY

AIRCRAFT SYSTEMS R&M

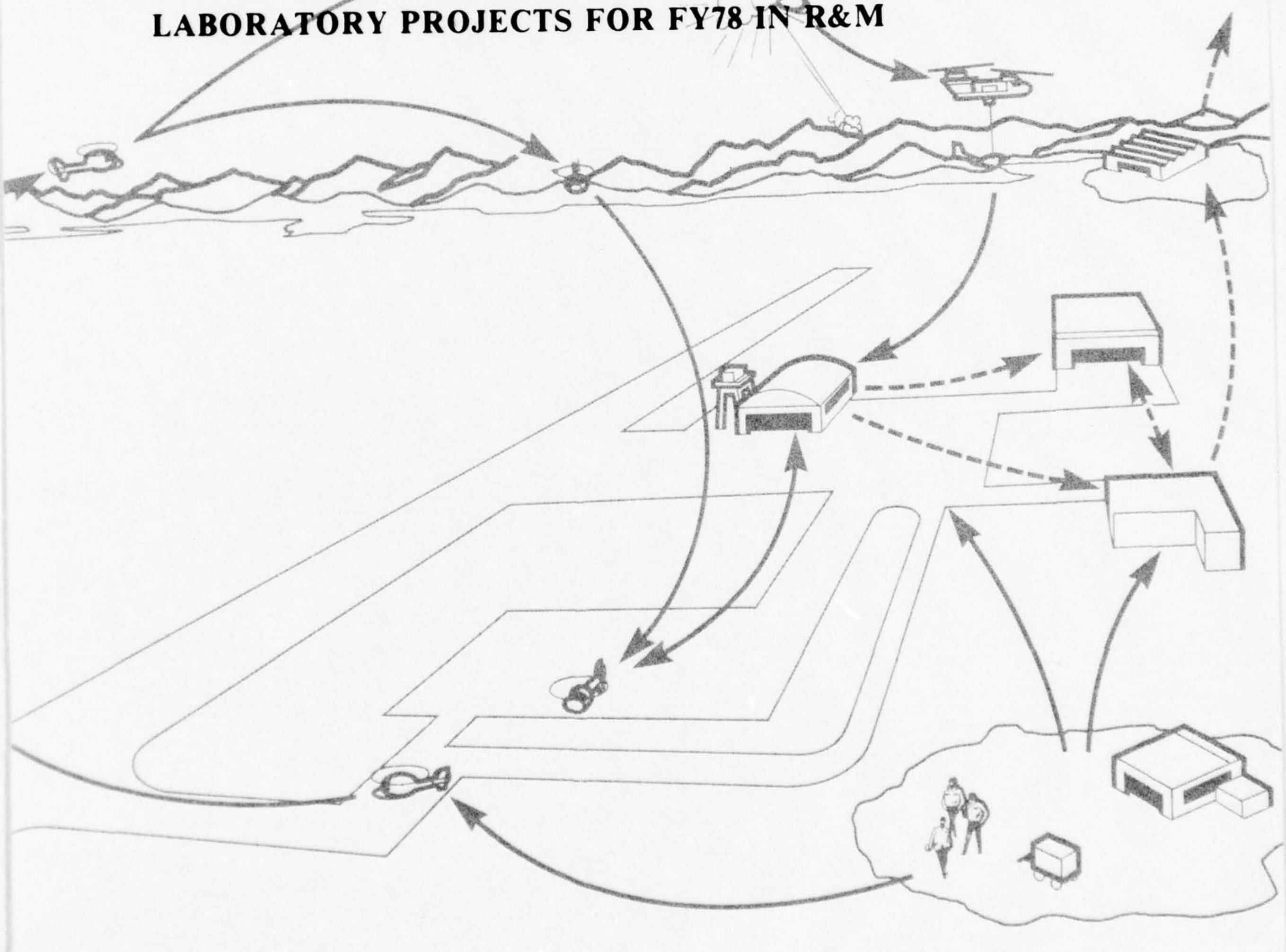
MODELING AND ANALYSIS

MAINTENANCE AND SUPPORT TECHNOLOGY

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

LABORATORY PROJECTS FOR FY78 IN R&M



INTRODUCTION

The basic R&D effort in this area is to conduct those exploratory and advanced development programs necessary to define the relationship between R&M quantitative characteristics and system, subsystem, and component design criteria/arrangements and test requirements. Once established, these relationships will allow full consideration of R&M, along with other systems engineering disciplines in the optimization of future Army aircraft. Close working interrelationship is maintained with all other disciplines to ensure that the R&M program is conducted in the most responsive manner possible and to maximize the probabilities of R&M being properly reflected throughout the development of new systems.

Army aircraft have been employed to accomplish a variety of missions and have generally accomplished those missions in an acceptable manner. However, the cost of supporting the aircraft has been extremely high and little effort has been made to reduce the life-cycle cost of any aircraft system. An analysis of current aircraft fleet experience has shown that maintenance and support costs over a 5-year period for the five basic operational helicopter types are about twice those of the original acquisition costs; and financial losses associated with aircraft losses due to noncombat reasons represent about 30 percent of the initial purchase price. Combat losses and worldwide noncombat losses, when compared over a 41-month period, were found to be approximately equal. Further, on an Army-wide basis, aircraft experience an average downtime of 25 percent due to scheduled/unscheduled maintenance and inspections; only a small fraction of this downtime is attributed to a lack of parts. Consequently, the combination of reliability and maintainability problems is taking a severe toll of Army resources.

An R&D program has been developed with the specific objective of providing significantly improved R&M characteristics for future aircraft. The basic program approach is to establish a clear quantitative/qualitative definition of current aircraft R&M characteristics, and to conduct subsequent analyses of design, test, maintenance, quality control, and technology changes that offer an improvement in terms of cost, mission reliability, availability, and other R&M related parameters. Because the R&M program utilizes Army aircraft experience, many of the improvements developed are directly applicable to the current operational fleet. An early major thrust of this program is the development and application of advanced analytical techniques for the quick and accurate quantitative analysis of R&M problem areas and proposed solutions, which are described in more detail subsequently. The short-term objective of the program is to concentrate on the use of current technology, or the development of new technology, to structure R&M design criteria, specifications, and guideline documents applicable to future aircraft systems. This can be accomplished through the use of advanced analytical methods, the development of improved subsystem technology, and the development of improved R&M test methods and procedures. The program described herein advocates the development of R&M technology at the component/subsystem level during the early phases of the program. As criteria/specifications mature, the emphasis shifts from specific component/subsystem R&M investigations to R&M design considerations, testing, and demonstration. Concurrently, as new requirements are developed that extend the capabilities of existing technologies, design concepts, etc., new starts at the component/subsystem level can be initiated as required to continue the improvement of aircraft R&M characteristics.

Four major areas of R&M investigation and research are described in the following subsection:

- Diagnostic
- Aircraft systems R&M
- R&M modeling and analysis
- Maintenance technology and support

Each area is considered a major subject for problem identification, analysis, and solution. The projected results of R&D efforts planned are presented in the form of trend curves and parameters.

The rational meshing of activites in the several areas of reliability and maintainability R&D to develop complete mission systems is shown on chart RM–I (located at the end of this section). The quantitative improvements in the state of the art in each area expected to be applicable to future missions are also shown.

TECHNOLOGICAL DISCUSSION

DIAGNOSTIC TECHNOLOGY

Diagnostic and inspection techniques currently used in Army aviation are inadequate with respect to detection of safety-related failure modes, minimizing unnecessary removals, and providing optimum fault isolation. In order to achieve optimum diagnostic capability it is recognized that the flow of activities outlined in figure RM–1 must be followed.

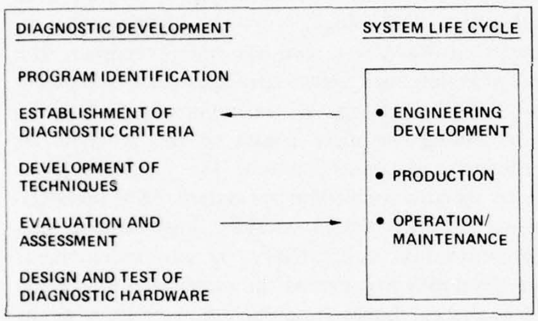


Figure RM–1. Diagnostic program flow diagram.

The areas where diagnostic equipment improvements are most likely to provide substantial payoffs include reduced accidents due to material failures, elimination of no-defect component removals, reduced supply downtime through prognosis of failures, reduced fault isolation time, and improved mission reliability. The magnitude of today's diagnostics problem is typified by recent statistics which indicate that up to 30 percent of all main transmission removals were found to have no failure during depot teardown inspections. Furthermore, it is estimated that approximately one-half of all mission aborts are caused by cockpit indications (chip detector lights, oil pressure gauges, etc.) on impending failures of components which are later found to have no defect. The above problems tend to occur because either the criteria for the diagnostic technique were inaccurate and/or the diagnostic technique employed failed to perform as anticipated. This situation has led to the approach which will be used in achieving an optimum diagnostic capability; that is, the failure mode symptoms and critical thresholds will be defined for proper criteria development followed by the development and/or selection of an affordable, cost-effective diagnostic technique.

Accordingly, the laboratory program in diagnostic technology is structured to be responsive to the reliability centered maintenance concept in order to achieve further reduction in the scheduled maintenance requirements. In addition to the goal of reducing maintenance costs and increasing equipment availability, it is desired that required maintenance actions can be performed by lower-skilled level personnel with less training than that presently experienced. Also, as system reliability increases as a result of R&M technology research, familiarity by maintenance personnel with the system may decrease to a point where diagnostic tools become indispensable for timely fault isolation and for proper failure identification. Emphasis to date has been on investigations of high frequency vibration analysis techniques for bearings and gears. Other areas of investigation have centered on the expansion of techniques for analyzing lubricating oil as an indicator of component condition. Recent efforts have indicated spectrographic oil analysis is limited to analysis of particles below approximately 8 microns while the engine and gearboxes are generating particles as large as 4000 microns during normal operation.

The advanced technology structures, components, and materials addressed in the Structures Technology Section of the Plan require new diagnostic and inspection capabilities for ensuring that reliability is sustained from the viewpoint of both structural integrity and fatigue tolerance. Diagnostics technology, which includes nondestructive test methods, provides one the greatest potentials for providing this assurance, while also offering a means for inspecting and repairing components that would otherwise be scrapped because of their unknown condition.

Another aspect of diagnostics is the utilization of sensed and observed signals, parameters, and condition information to logically analyze and fault isolate failures or out-of-tolerance conditions. One approach is the development of logic analysis techniques that can simplify the repair and maintenance function. For example, a logic calculator that assists the maintenance technician in fault isolation and malfunction identification (with or without connection to the hardware) could provide a high level of maintenance diagnostic capability for many components. Such equipment can reduce the skill level and training requirements to maintain advanced technology hardware. A test set which performs the above logic function has been developed and is being evaluated by the Air Force and Navy.

Another example is the development of inexpensive, easily manufactured items which require no technology advancements. One of these items was developed to monitor the condition of rod-end bearings so that maintenance personnel could make objective decisions on allowable rod end bearing wear.

The major objective of the near-term diagnostic technology program is the establishment of a clear insight into failure mode symptoms for helicopter gears, bearings, and other rotating machinery. Heavy emphasis is being directed toward the investigation of how oil debris can or should be used in assessing the condition of gear box assemblies; this area of work is prompted by the high rate of unnecessary removals and mission aborts occurring due to inadequate decision criteria currently being experienced through the use of various oil analysis concepts (chip detectors, filter checks, and spectrometric analysis). With the onset of super-fine filtration (3 micron) on the T700 engine, preliminary investigations are under way to define and evaluate techniques for analyzing the filter which now contains all the condition-indicating debris. Failure mode progression testing is being used to establish failure onset rates and to concurrently assess the usefulness of oil debris or vibration analyses in detecting and tracking the identified modes. Preliminary investigations of diagnostic system configurations are identifying options for establishing how various techniques may be combined into an operational system. Finally, a number of special diagnostic devices, such as mass fuel flow meters, are under investigation and are expected to provide improved information for field maintenance personnel assessing general engine performance trends.

The long-range diagnostic program is directed toward providing effective techniques and concepts for design components such as composite structure and advanced drive systems. These programs will be continually monitored to determine if specific special purpose diagnostic capabilities are required. Additionally, results of the fault-isolation criteria investigations will define specific device requirements such as ground-based maintenance aids for troubleshooting.

AIRCRAFT SYSTEMS R&M

ROTOR GROUP

Previous efforts under the R&M program have resulted in highly effective field repair concepts for rotor blades employing nonmetallic afterbodies (that portion of the blade between the spar and trailing edge). The UTTAS, CH-47D and improved blade for the AH-1Q/S will make use of this repair technology. Blade field repair has been emphasized because of the high external damage rate normally experienced by Army helicopters; moreover, only about 10% of current blades are repaired at field level. Application of the above mentioned repair concept is expected to permit 60% of all rotor blade repairs to be made at field level. Currently, an effort is under way to adapt the repair concept to metal blades such as the UH-1D/H, and CH-47A, B, and C. Future efforts for rotor blades will be directed toward achieving improved erosion protection and assessing repair limits of nonmetallic spars. As the Army turns more to nonmetallic blade concepts employing complex aerodynamic features, a need also exists for simple, effective condition-monitoring/inspection schemes that can be readily applied by field maintenance personnel in assessing the effect of damage, the quality of repairs, and the general performance characteristic changes that may occur through normal operation.

Rotor hubs have long been a source of frequent maintenance actions because of bearing and seal failures. Previous efforts under the R&M program have led to the development and application of elastomeric bearings to various rotor hubs with a resultant increase in MTBR's of over 600%. Although the elastomeric bearing technology is being successfully applied, a need exists to refine design criteria and concepts; specifically, the effect of operation in severe cold (below −25° F) is not fully understood. Additionally, the application of nonmetallic shims in these bearings offers significant weight benefits and should be examined. Finally, there are many applications of these bearings (flight controls, for example) that may offer considerable payoff.

The effect of vibration on helicopter reliability has long been recognized and has led to the emphasis on development of advanced vibration isolation concepts under the R&M program. It is apparent, however, that vibration reduction requires a significant investment in both aircraft weight and cost, and there is a practical limit to efforts in this area. Consequently, vibration problems will most likely always be in evidence and there is no practical way to predict their occurrence during design; this means that the test/fix cycle will be required to minimize the effect of vibration. Unfortunately, the only current effective

approach for testing for vibration effects is to fly the helicopter; this is an expensive process (over $10,000 per hour during development) and is often restricted because of limited R&D funds. A major effort under the R&M program is the development of an advanced concept for ground-based vibration testing. The concept would require shaking the aircraft with known hub forces and then developing a mathematical relationship between the forces and vibration levels throughout the aircraft; subsequently, the aircraft would be flown with actual vibration levels recorded for various maneuvers. In-flight vibrations would then be used to calculate the actual hub forces by using the previously developed mathematical model. The aircraft could then be shaken using the calculated hub forces to produce the full spectrum of in-flight vibrations. Ultimately, a single point vibration input could be established such that suspension of the aircraft by the hub would not be required. It is estimated that the cost of this type of testing would be about $500 per hour. The concept has large payoff potential for supporting PIP efforts as well as development programs. Typically, the integration of weapons or avionics packages could be achieved with minimal development flight testing. Additionally, lead-the-fleet testing could be accomplished and corrective actions developed before the operator knew a problem existed. The major benefit occurs because the design team can actually "see" the failure occur and can quickly assess the relative merits of proposed corrective actions.

Efforts in future years will be directed toward detailed R&M assessments of advanced rotor systems such as the advancing blade concept, tilt rotor concept, and controllable twist rotor. Each of these concepts is expected to require specific emphasis on maintainability to minimize both skill requirements and the needs for unusual ground support equipment and special tools. Close coordination between the R&M and Advanced Technology Demonstration program will be maintained to ensure proper integration of R&M activities within the systems engineering process.

PROPULSION AND DRIVE TRAIN SYSTEMS

Because helicopter transmission system designs have been inherently complex, they have caused numerous fail modes and high fail rates, and have necessitated short scheduled overhaul (TBO) intervals. Gearbox designs have not permitted field assembly and most failures result in chip contamination of the entire gearbox and subsystems. Shaft clutches, couplings, and bearings have short lives and serious failure consequences. Current transmissions have TBOs of about 1200 hr; the mean time between removals averages less than 1000 hr, with some as low as 450 hr. Helicopter powerplants, most of which are gas turbines, have many fail modes and a low mean time between removals. In military aircraft, main shaft bearings and oil seals have the highest fail rates. Fail rates of fuel-system components are high, often having serious consequences, and are expensive to correct. Combustor and turbine parts are highly susceptible to temperature cycling damage. Almost 30 percent of engine removals to the depot are due to FOD and compressor erosion damage. Erroneous fault diagnosis causes many unnecessary component and engine removals to the depot for repair.

A major effort in this area has been the analysis of design and test requirements necessary to approach effective on-condition maintenance (i.e., the elimination of scheduled overhauls using appropriate inspection criteria to determine when removal is required). Previous research has demonstrated the feasibility of the on-condition policy; however, that conclusion was based on analyses of component-level failure trends. It became apparent that part/piece failure trends must be established to properly address component level trens. Figure RM–2 provides the component level along with selected failure mode trends on a Weibull plot. Note that although the assembly level is indicating a constant failure rate (slope of 1.0),

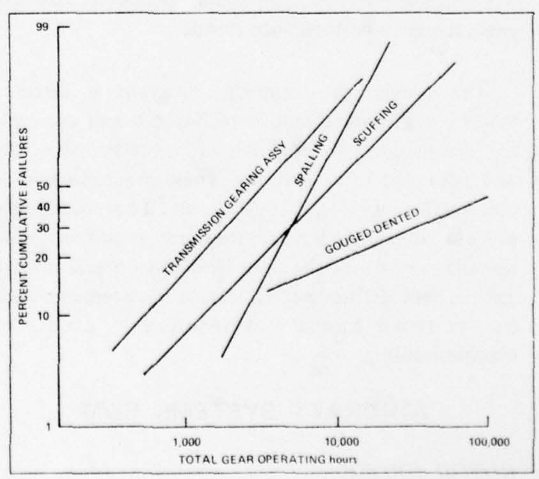


Figure RM–2. Weibull plot of typical transmission gearing assembly and associated fail modes.

some failure modes are indicating an increasing failure rate (slope less than 1.0). If scheduled overhaul times are either greatly increased or eliminated, the independent failure mode trends will cause the assembly level failure rate to increase. Such information provides the basis for identifying those part/piece items that must be improved to gain maximum return through implementation of an on-condition maintenance policy.

For transmission drive systems, in-depth analyses can be performed for new concepts to reduce complexity, define and test new materials, and to establish design criteria to eliminate scheduled overhauls. Analyses and tests can be conducted to identify ways to confine metallic failure debris to a small area within a transmission and to permit overhaul of gearbox components rather than overhaul of whole assemblies. New-concept clutches and shaft couplings can be developed and tested for high-speed applications. For long-range applications, simplified engine-rotor-drive systems can be analyzed and developed. Research and development efforts in helicopter powerplant bearings can encompass extrapolation of contact bearing technology and development testing of noncontact bearing concepts. Simplified fuel systems can be developed, including all electronic scheduling. Simple, efficient environmental debris separators can be developed and tested, along with compressor materials having greater resistance to erosion damage. Advanced hot-section materials and cooling techniques can continue to be investigated and developed to eliminate scheduled overhaul requirements. Development of accurate, simple diagnstic systems can continue to be pursued to eliminate costly, no-defect removals from service. For long-range application, use of less corrosive, more efficient fuels can be investigated. Improved design and development test concepts, coupled with establishment of advanced statistical techniques, can allow the establishment of on-condition maintenance concept for first-fielded items. Development of design arrangements that allow fault isolation to field replaceable modules may offer significant reductions in parts costs and depot labor requirements.

For drive systems, reduced complexity and elimination of scheduled overhauls can yield greatly reduced life-cycle costs while permitting higher speeds and performance. Improved clutches and couplings can enhance flight safety and further reduce costs. Development of fully modularized engines that have no scheduled overhaul requirements and that are capable of unlimited operation in environmentally hostile conditions can greatly reduce life-cycle costs. Elimination of bearing and hot-section failures can significantly increase flight safety. Modular maintenance and accurate fault diagnostics can also greatly reduce future life-cycle costs.

Sought-after improvement trends in transmission and engine removals in terms of TBO and TBR are shown in figure RM–3. The figure shows the expectation that by about 1981, the technology will have been developed to a state that will enable the institution of a philosophy for maintenance of powerplants and drive trains based entirely on replacement without provision for overhaul.

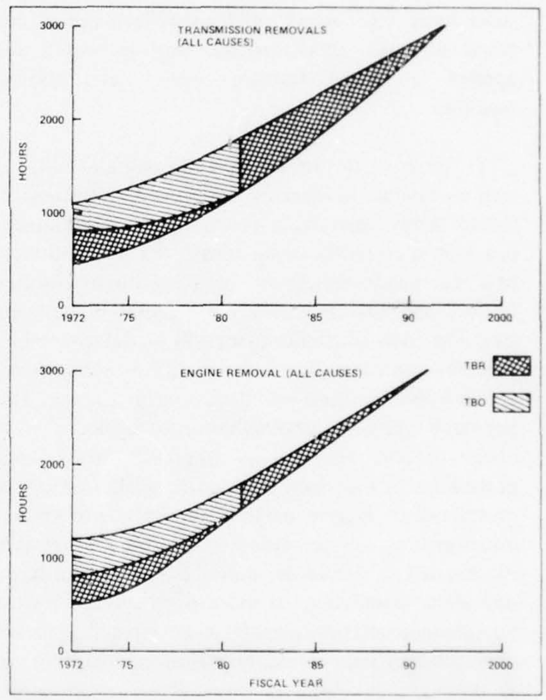


Figure RM–3. Propulsion and drive train improvement goals.

Many of the factors discussed in this area of R&M were also addressed in the presentation of the R&D Plan for Propulsion and Drive Trains. The interface between these two technologies is obvious; therefore, the program plans for both have been coordinated and integrated. This is another prime example of the fact that technological development in one area of the program affects others.

FLIGHT CONTROLS AND UTILITY SUBSYSTEMS

Premature failures of flight control, hydraulic, electrical, fuel, and other utility subsystem components are causing excessive maintenance and logistical burdens, poor mission reliability, accidents, and excessive costs in current inventory aircraft. Avionics subsystems, for example, are sources of frequent failures, and contribute heavily to mission unreliability and subsequent maintenance action. Reasons for these failures vary, depending on the component, but they include inadequate design criteria, test requirements and procedures, poor maintenance procedures and practices, inadequate quality assurance provisions, and lagging technology. Many of these deficiencies exist, in addition, because of past policies and procedures under which off-the-shelf helicopters, certified to FAA specifications, were procured and applied to Army training, utility, and combat missions.

To improve the reliability and maintainability, as well as aircraft availability and cost-effectiveness of future Army aircraft, a research and development program is currently being considered that will identify the major deficiencies existing on inventoried aircraft and determine the basic causes of deficiencies. The basis for deficiencies will be determined by selecting representative components as subjects for detailed investigations into development and use. This approach will allow determination of inadequacies in design or test requirements, improper maintenance procedures or practices, inadequate quality assurance provisions, or lagging technology. Results of various investigations will generate a sound basis for revised specifications, standards, practices, and procedures; will allow stipulation of more precise requirements for future generation aircraft; and can result in immediate product improvement applications. In addition, as lagging technology is detected in certain areas, R&D efforts will be initiated to advance the state of the art. Typical efforts currently under way include detailed quantitative/qualitative R&M analyses of mechanical flight control elements (cables, rod end bearings, etc.), hydraulic actuators, electrical system components, stability augmentation systems, and fuel system components.

In conjunction with the major R&M thrust, a continual cognizance will be maintained of other advancements in technology. Efforts can be initiated to conduct R&M assessments during these development programs and to participate from an R&M standpoint, in these ongoing projects – the objective being to enhance R&M features along with performance, weight, and cost considerations. Sought-after improvement trends in flight control and utility subsystem reliability and maintenance burden are shown in figure RM–4. Statistical data regarding these subsystems are somewhat limited but they do indicate that the distribution of repair times is rather dense and they do support the continuous relationship between reduced failures and reduced maintenance depicted in figure RM–4.

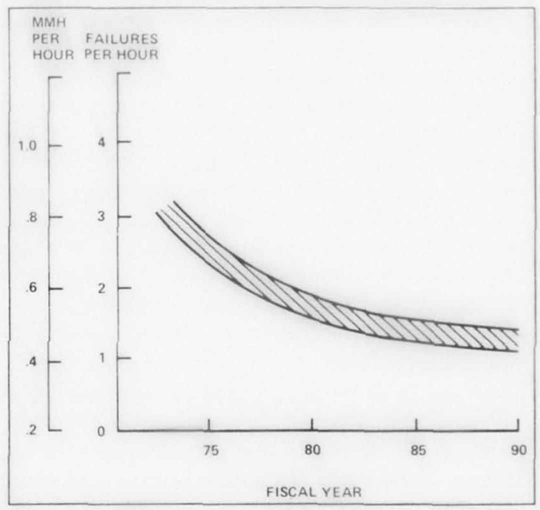


Figure RM–4. Flight controls and utilities systems improvement goals.

The R&D approach to reliability and maintainability can result in:

- Accurate and definitive design and test criteria.
- Accurate and specific design and test requirements.
- Detailed maintenance manuals.
- Simpler maintenance procedures.
- Fewer maintenance actions.
- Improved or advanced technology to enhance R&M.
- Accurate definition of the Army aviation operational environment.
- A thorough basis for evaluating contractor proposals.
- Improved program management techniques.

- Product improvement potential in areas of detailed investigation.

In more general terms, specific information will be made available for application to the improvement of reliability and maintainability of future Army aircraft systems and of the second generation of these systems.

The ultimate R&D objective is to have completely developed and proven off-the-shelf engineering design of advanced mission systems. See the Aircraft Subsystems section (AS) for additional discussion of reliability aspects of these systems. The R&M plan is completely integrated with R&D efforts described in that section.

STRUCTURES AND AIRFRAME

Statistical analyses of operational R&M data have shown that approximately 25 percent of all the unscheduled maintenance on helicopters is on the airframe (primary and secondary structures). This statistic is virtually constant regardless of helicopter class (utility, observation, transport, etc.). Airframe maintenance is the driving requirement for major aircraft overhauls (3000 hr overhaul cycle for UH–1) and this overhaul is dominated by structural repair, including a 90 percent transparent structures replacement rate. Skin cracks, defective fasteners, failed door hardware, rivet replacement, windshield deterioration and access panel failures are typical failures experienced. Additionally, the correction of combat damage involves considerable man-hours because of the complexity of the sheet metal rework. Considerable improvements are required in airframe R&M characteristics of future systems.

The current R&D program in R&M for attacking the above situation is structured to include both short- and long-range efforts. Efforts are being directed toward obtaining a better understanding of secondary structures and windshield problems and determining potential changes required in specifications and concepts necessary to provide immediate fabrication, lab testing, and operational evaluation of specific design concepts; these efforts can provide the basis for recommended approaches applicable to aircraft systems in the near-term timeframe. Reliability and maintainability evaluations of advanced structures concepts will be a main R&D thrust in the upcoming years. Specifically, during FY77-78, a thorough R&M assessment of near-term candidate advanced structures concepts will be accomplished. Results will be utilized to develop inputs to the design requirements for the planned Advanced Structures Technology Demonstration program. Additionally, follow-on efforts to develop field repair concepts for advanced structures will be accomplished. Long-range R&M evaluations of structures should include consideration of various other composite materials and fabrication concepts. Specific effort can be directed toward maintenance concepts for integrated and parasitic armor design arrangements. Selected fasteners and bonding concepts potentially usable for field maintenance can also be subjected to detailed laboratory and operational evaluations.

The above efforts, coupled with the significant reduction of maintenance burden envisioned as a result of rotor vibration isolation, have a high payoff potential in terms of increasing aircraft availability and decreasing the number of skills required of maintenance personnel. It is expected that the production version of UTTAS will benefit directly from the secondary structures and windshield efforts. The curve in figure RM–5 is considered conservative in predicting the trend for MMH/FH decrease for the period in question (based on utility-size vehicles). The data in figure RM–5 were developed independent of cost. It is highly unlikely, however, that the reduction in maintenance burden can be achieved without some increase in aircraft initial cost. Consequently, the structures and airframe R&M program will require continuous cost analyses to ensure that the maintenance burden decreases are not offset by increased initial cost. It is expected that as the program develops, and as suitable cost data are available, figure RM–5 will be replaced with a combined cost and maintenance burden objective trends.

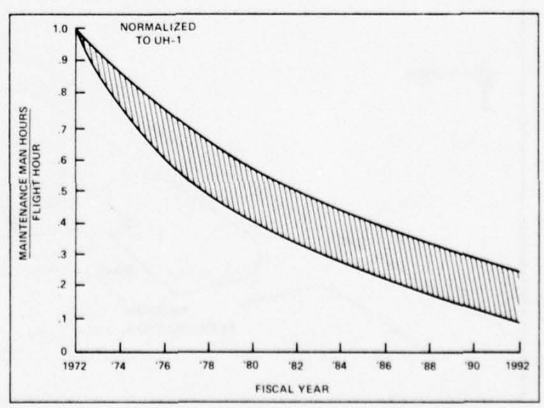


Figure RM–5. Structure/airframe improvement goals.

Again, the R&M and the structures and materials R&D plan have been coordinated and integrated to provide for the essential interchange of technological knowledge and developments.

MODELING AND ANALYSIS

As operational Army aircraft increase in sophistication, the estimation of their reliability, maintainability, required support, and operational capabilities also becomes increasingly complex.

The multi-disciplined aspect of reliability and maintainability requires a system-level approach to address properly the combined design, operational, maintenance, and support considerations that must be made when R&M analysis is performed. Both system- and component-level considerations are required.

At the system level, special attention is devoted to large-scale simulation efforts, principally through the ARMS (Aircraft Reliability and Maintainability Simulation) analysis approach, to ensure that all contributing factors can be reasonably addressed. On-going efforts to advance and improve laboratory R&M simulation capability will assure that new concepts in design, maintenance philosophy, diagnostics, and aircraft mission scenarios can be evaluated and the R&M implications to design identified. Figure RM–6 portrays the simulation process that is addressed. The ARMS analysis provides the tools that enable the laboratory to assess the effect and interaction of reliability, maintainability, safety, vulnerability, and survivability parameters on the tactical performance, mission success, availability, resources, and operational costs of current and future (conceptual) Army aircraft.

At the component level, detailed analysis of R&M parameters can be directly addressed as they relate directly to designed hardware function and performance. An understanding is required of specific failure modes, functional and physical characteristics, and of those factors that cause malfunctions and failures. Also, the resource expenditures and costs associated with designs that meet R&M specifications significantly affect the philosophy of design for maintenance. Presently, emphasis is placed on design for on-condition maintenance. Investigations have shown that many components can be designed for

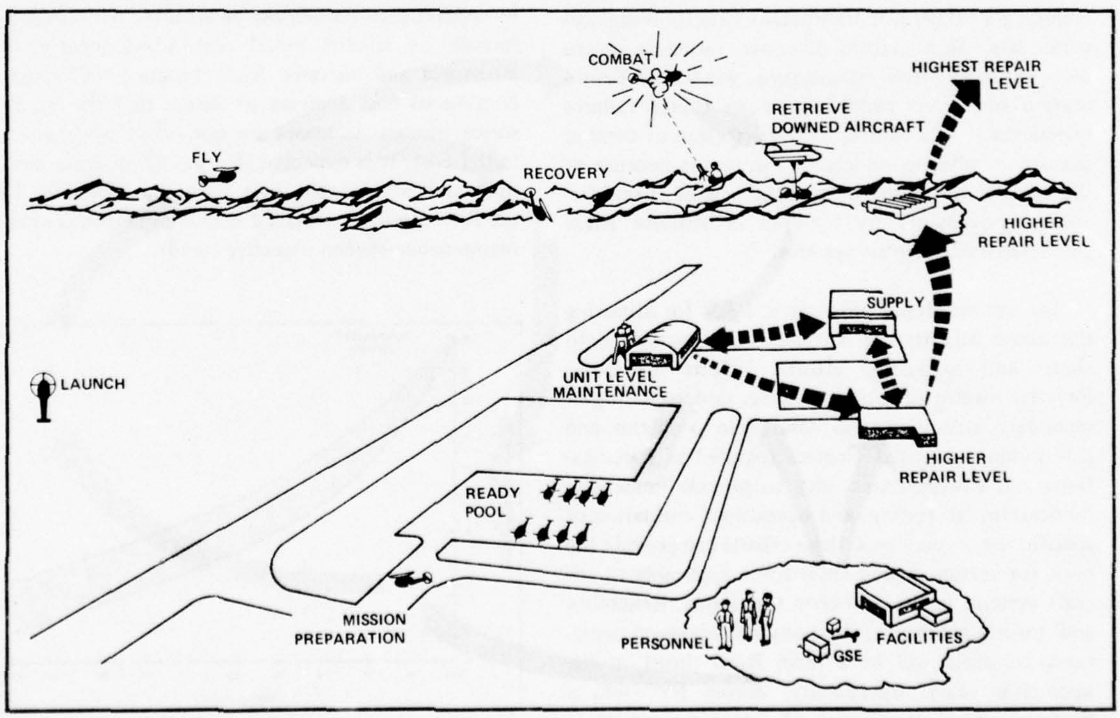


Figure RM–6. ARMS model.

on-condition, which can eliminate the need for a TBO (time between overhaul). Certain fundamental considerations dictate if and when a TBO should exist. Figure RM–7 shows how cost factors (time or dollars) vary with the unscheduled/scheduled maintenance ratio, and the TBO (scheduled overhaul) point as measured in standard deviations from component average design life. Elimination of catastrophic failure modes and the use of cost-effective condition-monitoring can eliminate an established TBO (essentially, the TBO is extended to such a large value that it does not exist for all practical purposes). Simulation and analytics can provide insight into the many facets of R&M technology that require attention for defining and evaluating trade-offs that must be made in the design process.

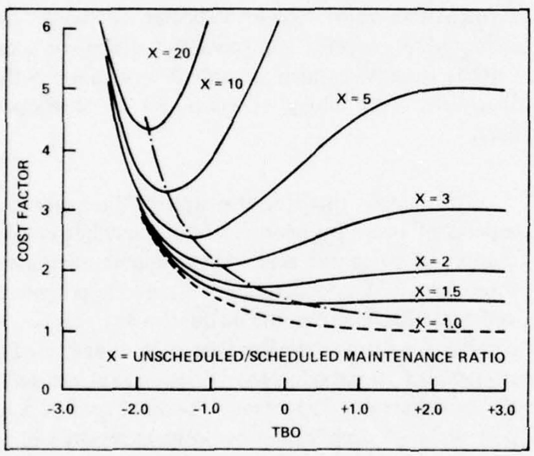


Figure RM–7. Cost factor influence on TBO selection.

The Modeling and Analysis program is being expanded to address a wide range of operational analyses where R&M are considered significant issues, thus resulting in a generalized systems analysis approach that benefits the entire Army R&D technology development program. As an example, an analysis methodology was developed to evaluate a number of helicopter cargo handling system concepts. The evaluation considered the physical constraints of the cargo system itself, such as loading and unloading times, number of sorties required per ton load, reliability, availability, and maintainability, as well as the effect on aircraft maneuverability and vulnerability. This methodology model was developed especially for the evaluation, identified as Assault Support Helicopter Operations Simulation (ASHOPS), and combined existing model EVADE (Evaluation of Air Defense Effectiveness), developed by the U.S. Army Materiel Systems Analysis Agency (AMSAA) with PIPE (Product Improvement Program Evaluation), developed under contract by AVRADCOM. Figure RM–8 illustrates how each of these models contribute to the overall evaluation. The analysis provides measures of life-cycle cost, operational effectiveness, productivity, and performance in both combat and noncombat situations. The analysis technique is used to assist in establishing research priorities in terms of benefits achieved, costs incurred, and risks assumed.

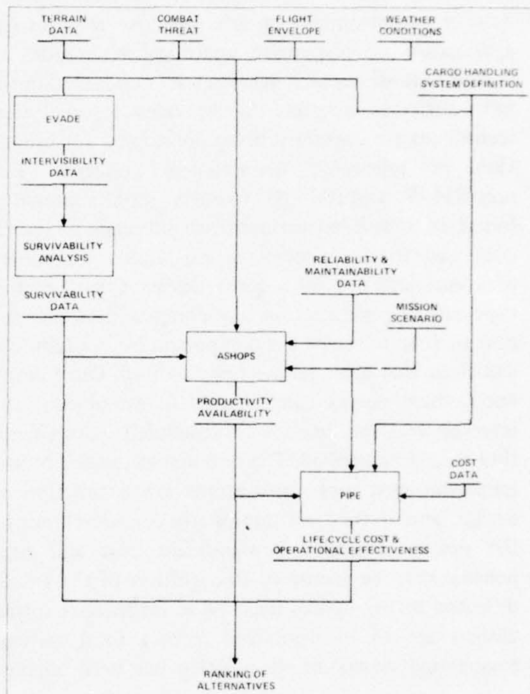


Figure RM–8. Assault support helicopter operations simulation.

Further research is required to develop new techniques in the areas of R&M testing, maintenance logic analysis, and R&M analysis of the effect that advanced structures components will have on the ability to operate, maintain, and diagnose the condition of future aircraft.

MAINTENANCE AND SUPPORT TECHNOLOGY

Current operational helicopters are experiencing extensive maintenance downtime and cost for both scheduled and unscheduled maintenance. In many cases, as explained in detail later in this section, inadequate consideration of R&M characteristics

during design created the problem. It is equally evident, however, that the lack of proper analysis techniques has also produced maintenance concepts that are less than optimal for the aircraft systems as they exist today.

The principal objective in the Maintenance Technology and Support Materiel area is to develop the relationship between design and maintenance concept variations such that future aircraft can be operated in an optimal manner with respect to cost and effectiveness. Accomplishment of this objective requires the application of responsive analytical techniques to ensure that all research activities are conducted in the most efficient manner. As an example, analytical techniques are currently being considered for evaluation of scheduled maintenance concepts. Figures RM–9 and RM–10 indicate variations often found in scheduled maintenance intervals and total cost and total maintenance man-hours (scheduled plus unscheduled) for a given design. Curves of this type can be generated for any component where the cost or time to renew the component before failure is less than that after failure has occurred. Once developed, these curves can be used in establishing the intervals and the amount of scheduled maintenance that should be applied. The boundaries created by the minimum cost and time points are a function of design, and if they are improperly considered during the design selection, a significant cost and time penalty may be incurred. Recognition of the trends reflected in the figures must be in evidence if future designs are to be optimized from a total systems engineering viewpoint. If a design has been selected prior to the above analyses, a maintenance support recommendation may be obtained through use of measured R&M statistics; an approach similar to this is being used in the analysis of the scheduled inspections described beow. Special emphasis is directed toward the effect of aircraft missions on design, support equipment, and maintenance concept alternatives. Typically, the Army's desire to deploy helicopters on the mid-intensity combat field demands a critical assessment of maintenance requirements as they relate to a limited duration war. Maintenance criteria, as an example, should change significantly during combat as opposed to peacetime operations; furthermore, benefits will be derived from quick-fix combat damage repair kits which provide a limited operational capability. The Army has experienced significant problems in the area of fault isolation (troubleshooting) which indicates a need for improved procedures and (possibly) diagnostic aids. Criteria for devices such as those described under the Diagnostic Technology program can be developed here.

Effort under this area also stresses the qualitative aspects of design for maintainability including consideration of personnel skill levels, support equipment interfaces, and application of diagnostic/prognostic concepts. Results from the qualitative analyses can be combined with quantitative data such as described in paragraph 1 to provide a total responsive effort under the broad area of Maintenance Technology and Support Materiel. Application of program results will be achieved through proposed improvements to existing specifications and standards and the development of

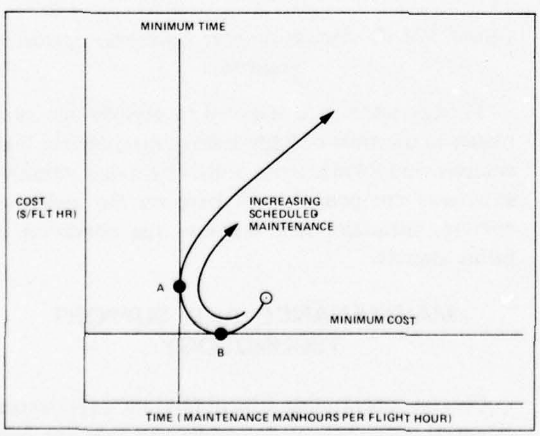


Figure RM–9. Time and cost relationship to scheduled maintenance where time sensitivity is greater than cost sensitivity.

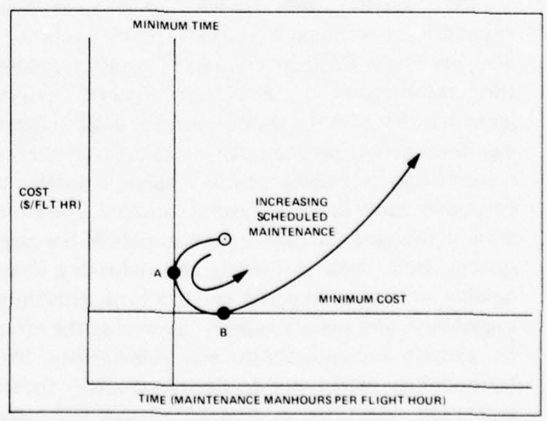


Figure RM–10. Time and cost relationship to scheduled maintenance where cost sensitivity is greater than time sensitivity.

design guides. Satisfaction will be achieved through an aggressive R&D program.

The short-range maintenance technology program is addressing mid-intensity maintenance issues (including combat damage repair), improved fault isolation techniques, and equipment and assessments of selected maintenance aids. Additionally, continued effort on investigating scheduled inspections required for both peacetime and combat operations is planned. Each of these efforts is expected to result in specific concepts/techniques that will require further investigation and test during the 1979-81 timeframe. Generally, all efforts under the near-term maintenance technology program are aimed at gaining increased aircraft availability at very low investment costs; in fact, some may require a change in procedures only. Other efforts such as the improved alignment indicator for drive shafts and the integrated rod end bearing wear indicator will require a modest initial investment and can be adapted to both current and new development systems.

It is expected that the maintenance technology program will have as its main objective the continuing support of all advanced development projects within the total R&D program. Typically, during the Advanced Technology Engine (1500-hp demonstrator) program, certain maintenance design investigations were conducted that led directly to the adaptation of significantly improved maintenance design concepts for the UTTAS engine currently under development. The Advanced Technology Engine (ATE) maintenance investigation included maintenance information demonstrations and evaluation of logistical support considerations. Efforts of this type made during the advanced development period are normally expected to provide a greater ayoff per dollar than efforts made at any other period in the development of technology. The 800-hp advanced technology engine, tilt rotor air vehicle, advancing blade concept, and advanced drive system are representative of the advanced technology concepts requiring intensive maintenance assessments prior to entering full development programs. These programs (along with efforts to develop new concepts in instrumentation and design that will allow for improved diagnostic and prognostic capabilities) typify the type of effort that is required to achieve improvements in maintenance technology. In this manner, maintenance technology will help improve the R&M characteristics of design. Efforts in this area are in conjunction with the Ground Support Equipment discussed in the Mission Support Section of the Plan under the heading of Test and Diagnostic Equipment.

The payoff of R&D efforts in maintenance technology, coupled with improvements in reliability, is expected to take two forms. The first will be a significant reduction in total maintenance downtime that will be reflected in increased aircraft availability and reduction in total maintenance personnel requirements. The second will be a decrease in maintenance-induced aircraft accidents through the simplification of maintenance tasks. Figure RM–11 shows the sought-after improvement trend in reduced maintenance downtime over the time period covered by this document. The curve is considered applicable to a utility-sized vehicle, but is representative of that expected with all types of Army helicopters. The starting value of downtime used in figure RM–11 is based on operational data extracted from DA Form 1352s for the UH–1H helicopter. This value includes certain supply and administrative downtimes that are not necessarily related to the design; however, the trend for maintenance reduction is considered valid and may be used to reflect projections for any desired definition of downtime (inherent, achieved, or operational).

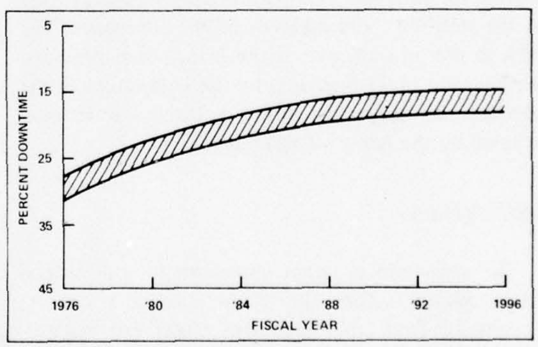


Figure RM–11. Maintenance technology improvement goal.

Advanced techniques and methods for aircraft condition-monitoring have recently been developed by AVSCOM. This unique application of relatively simple inspection procedures is titled, "Aircraft Condition Profile." Briefly stated, the method consists of selecting basic airframe "indicators," such as loose and missing rivets, structural alignment, corrosion, etc., and assigning coded symbols that represent the indicated condition and gradations between good and poor. The coded information is readily translatable to

computer programming or may be visually interpreted to yield a rapid and accurate assessment of the aircraft condition. It has proved to be a highly efficient maintenance monitoring system and a powerful management tool. It can be used to establish thresholds of airworthiness and serviceability as well as providing criteria for selection of aircraft for cyclic depot maintenance. It has marked the end of an era in which the traditional criteria of accumulated flying hours and chronological time in service were the sole criteria, regardless of the aircraft's actual condition. As more data are accumulated and more experience is gained with the aircraft condition profile, the potential for its contribution toward RDT&E efforts in the reliability and maintainability field will be magnified.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in the Technology Introduction Section of the Plan. This section applies that process to the reliability and maintainability disciplines. The OPR is not an objective of the Plan, but is provided to show the procedure used by the Laboratory in the selection of programs within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the R&M discipline can be established from the near-term quantified achievement goals listed in chart RM–I. It is important to note that the R&M technology is oriented toward better utilization of resources as opposed to primarily advancing the performance of designed hardware; as such, it identifies the tradeoffs and areas of compatibility between resources and performance. The R&M technology establishes a system of checks and balances in the design process which is reflected in the following R&M objectives.

- Establish diagnostic and prognostic concepts to improve V/STOL R&M characteristics.
- Develop advanced R&M component design concepts which contribute to achievement of 25% reduction in support costs and a 30% reduction in maintenance downtime.
- Establish R&M analysis techniques for new systems. Develop criteria and concepts to achieve 25% reduction in maintenance support costs. Develop concepts for 30% reduction in maintenance downtime.
- Establish testing methodology for R&M which will contribute to achievement of 25% reduction in support costs and 30% reduction in maintenance downtime.

PROGRAM PRIORITIES

General. Table RM–A presents, in a prioritized listing, the R&M technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. R&M technology subdisciplines are represented by the following major topical areas (listing is not in prioritized order):

- *Diagnostics.* This pertains to the ability to determine the condition and to predict condition progression of components through the use of instrumentation and/or indicating devices for purposes of enhancing reliability and maintainability characteristics. This includes sensors or pick-ups, signal processing equipment, logic circuiting, indicating devices, and those devices and techniques which allow the functional hardware such as engine, transmission, rotor blades, etc., to be monitored for maintenance, replacement or overhaul determination.
- *Aircraft Systems R&M.* This area pertains to the inclusion of R&M philosophy in the design concepts of components with attention focused on those designs that will provide for improved reliability in the component design function and/or provide for ease of maintenance in a cost effective manner through reduction of maintenance time, special tools, etc. Component level improvements yield visible and measurable results and offer improvements that the user can see and understand. System level improvements in R&M are often unmeasurable and less detectable than improvements in component design.

TABLE RM–A
PRIORITIZED R&M OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Maintenance and support technology	I	• Rotor group	I	• Life cycle costs	I
• Diagnostics	II	• Propulsion and drive	II	• Reliability	II
• Aircraft systems R&M	III	• Flight control	III	• Maintenance burden	III
• Modeling and analysis	IV	• Aircraft subsystems	IV	• Availability	IV
		• Airframe/structure	V		
		• Weapons support systems	VI		
		• Avionics	VII		

- *Modeling and Analysis.* As related to R&M, modeling and analysis considers the mathematical functions, statistical relationships, and algorithms of both deterministic and simulation type that provide the technical understanding of design maintainability and reliability properties, and relates those design characteristics to other factors of operation, maintenance, and support which have a bearing on the design process. Also included in this subdiscipline is R&M testing methodology that addresses the issue of measuring and tracking R&M parameters that are often complex functions of thermal, physical, electrical, and mechanical properties coupled with conceptual properties of maintenance, logistics, and operations. The ability to accurately assess and understand factors as they pertain to direct operating cost effectiveness of military aircraft missions, etc., is closely related not only to knowing what the R&M effects are on aircraft but also to determining how to measure, test, and assess what the reliability and maintainability characteristics are for helicopter systems. Just as it is important to have wind tunnel test procedures to measure aerodynamic properties, it is necessary to develop test methodology for measuring R&M parameters in an efficient manner.

- *Maintenance and Support Technology.* The methodology addressed in this area allows the design objectives for performance, reliability, and maintainability to be met and sustained through proper integration of the design philosophy with the maintenance and support philosophy and concepts. The goal is to develop the relationship between the functional hardware design and the maintenance concept and theories in such a way as to allow future aircraft to operate in a highly cost effective and reliable manner. The Army's strong desire to deploy helicopters on the mid-intensity combat battlefield coupled with the need to reduce maintenance personnel requirements in both terms of numbers and skills causes this area of work to be most important. Furthermore, results of efforts in this area are often readily adaptable to current operational aircraft as well as developmental systems. Issues regarding combat damage repair, deferrable maintenance criteria and maintenance aids are considered critical and offer significant payoff at a very low investment cost.

Vehicle Subsystems. Vehicle subsystems, as related to R&M technology, are categorized as follows:

- Rotor group
- Propulsion and drive
- Flight control
- Aircraft subsystems
- Airframe/structures
- Weapons support systems
- Avionics

These subsystems essentially cover the entire aircraft and are consistent with the scope of consideration that must exist when addressing R&M technology.

System Effectiveness. In the area of systems effectiveness, the fundamental influence of R&M technology is reflected in the resources required to operate and maintain the designed hardware. Therefore, life-cycle costs are greatly affected. Mission reliability and the availability of aircraft to perform the mission is a direct product of the level of R&M technology applied. The total maintenance burden when considered in light of the mission that the aircraft must perform, bears a one-to-one relation to the maintainability aspects of the design.

Priorities. With reference to Table RM–A, the R&M subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

General. The OPR procedure described above was used as an aid in the development of the FY78 program elements for the R&M R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 R&M technology development program.

The major R&D thrusts pertaining to the R&M technology are discussed in the following paragraphs.

Maintenance and Support Technology – Priority I. One of the major causes for R&M design criteria not being closely achieved or reflected in production aircraft is the lack of testing methodology which would allow for deeper understanding of how R&M specification and requirements can be measured and demonstrated in a practical and cost effective manner. Coupled with an improved methodology for testing and measuring would come on improved knowledge of how to correctly specify and relate R&M parameters to other design characteristics. The Laboratory has expended considerable resources to develop design criteria for several helicopter subsystems, and the program should now be augmented by a concentrated effort to develop the testing methodology to ensure that the R&M design criteria developed can be effectively measured and related to other system parameters through proper testing techniques and analyses.

Development of Diagnostic/Condition Monitoring Capability – Priority II. There are several alternative methods available for improving overall aircraft R&M characteristics. These include inherent design properties, aircraft support concepts, and improved diagnostic sensoring and condition monitoring. The latter provides one of the most feasible methods for improving aircraft R&M, while having little or no effect on current design methods and performance characteristics as opposed to alternative methods of improving R&M. Also, the cost of such an approach is relatively independent of costs associated with the development of functional aircraft components that are monitored, since independence between function for performance and function for diagnosis can be maintained. The state of the art is capable of providing improved diagnostic/sensoring capability on a cost effective basis. It is the application of this capability to improve Army aircraft R&M that is presently lacking. The current AIDAPS program represents only one approach to an improved diagnostic/sensoring capability. Laboratory developed concepts will be applicable not only to future designs but also to the current fleet.

Aircraft Systems R&M – Priority III. Although many system factors contribute to determining the value of R&M characteristics exhibited by Army aircraft, the primary factor with the most influence and sensitivity is the actual component design. Extensive investigations to date in the R&M program to define areas for improved design – modularization of transmissions, vibration effects on component lifetimes, on-condition maintenance requirements, and elastomeric design criteria – point out the potential that exists for greatly improved component R&M properties. Logistics concepts, maintenance plans, and repair and overhaul procedures are all after-the-fact contributors to improving R&M compared to the design itself. The high dollar cost of aircraft components and the high risk and cost of secondary effects of component failures provide the necessary incentive to continuously improve component design R&M. Illustrative of the importance of secondary failure effects is the total loss of a multimillion dollar aircraft because of the failure of a door latch. On a cost basis alone it is very effective to incorporate R&M considerations at the component level. Redesign of current fleet components is not always practical; therefore, advanced component R&M design should be directed primarily at future aircraft.

Modeling and Analysis – Priority IV. The need for advanced R&M analysis grows with the complexity of

the logical alternatives for designing and maintaining advanced systems. The interdependencies and operational influence of one subsystem with respect to another become lost unless the relationships in mathematical models and equations are sophisticated enough to properly explain the total phenomenon. To illustrate, the laboratory does not at the present have satisfactory analytical tools developed to treat the system level influence of sophisticated diagnostic and sensoring capability as addressed in Priority II. The structuring and treatment of this problem must be included in simulation and deterministic R&M analysis such as ARMS to provide analytic visibility.

LABORATORY PROJECTS FOR FY78 IN R&M

INTRODUCTION

The research program in reliability and maintainability technology is addressed at the (6.2) exploratory development and (6.3) advanced development levels. The objective is to develop advanced technology and equipment with improved military operational capabilities for Army aircraft through improved reliability and maintainability characteristics.

Research in this area is conducted by the Applied Technology Laboratory, Fort Eustis, Virginia, and the Propulsion Laboratory, NASA-Lewis Research Center, Cleveland, Ohio.

The Applied Technology Laboratory programs constitute the major portion of the R&M effort, which includes both 6.2 and 6.3 work, and encompasses all subdisciplines addressed in the program.

The Propulsion Laboratory program is in the area of propulsion and, as such, focuses on gas turbine R&M characteristics.

DESCRIPTION OF PROJECTS

Reliability and Maintainability Technology. Project 1L262209AH76-TA IV is an exploratory development effort to develop advanced technology and equipment to provide advanced military operational capabilities of Army aircraft in a cost-effective and timely manner through improved reliability and maintainability characteristics. Specific requirements for current and near-future aircraft are given primary consideration, together with full support of project-managed programs such as UTTAS and AAH. The major goals that are supported reflect improved durability, reliability, maintainability, and mission effectiveness. The identification of R&M issues associated with current fleet aircraft is ongoing. Design analysis is performed and new concepts are assessed. R&M analyses consider the joint effects of design, operation, and maintenance.

Previous efforts have concentrated on determining the causes of R&M deficiencies in currently inventoried helicopters and conducting concept investigations to improve system- and component-level R&M characteristics. It has been determined that the design, test, and acceptance criteria are not sufficient to meet R&M requirements. Also, major factors causing component removals are often external to design, but must nonetheless be addressed. The influence of rotor-induced vibration on component failures has been quantified and judged a significant burden on the maintenance posture.

Investigations and testing of blade segments for sectionalized and highly repairable rotor blades have been addressed. Tests on bearingless fiberglass tail rotors have been performed. Effort has been initiated and is continuing to develop detailed design criteria for elastomeric bearings, which offer big payoff in terms of R&M. The on-condition maintenance concept has been investigated, with results indicating that its application should be pursued where technology and economics allow. In-house tests of high-speed oil seal concepts have been promising, and abradable and rub-tolerant gas-path seal materials have been evaluated that will result in a seal material that is more rub-tolerant. Exploratory development design has been done in the areas of tapered roller bearings, engine erosion protection, and a fabricated transmission housing. Investigation to identify and recommend corrective revisions to deficient documentation for helicopter flight control and utility systems has been addressed. Preliminary design and qualification criteria for secondary structures and transparent enclosures have been established and concepts for super-hard canopy coatings have been developed. In-flight vibration surveys are completed on UH–1, CH–54B, OH–58A, and CH–47C aircraft to correlate failures with vibration parameters. Hydraulic hose chaffing tests are completed. The probabilistic R&M simulation effort has been well established as a useful analysis tool. Investigation of acoustic signal analysis as a diagnostic tool has been addressed, as have several advanced sensor concepts that offer promise of improving the condition-monitoring capability. Oil debris monitoring also is progressively addressed and fatigue crack detection devices have been prototyped.

All of these efforts are directed toward improving the reliability, maintainabiity, and diagnostic posture of Army aircraft through advanced technology.

Reliability and Maintainability. Project 1L263209DB38 is an advanced development effort to provide comprehensive component and system reliability and maintainability credibility by validating improved R&M designs, test, and acceptance criteria, and by establishing confidence in advanced concepts developed under 6.2 efforts. Successful results of this work will provide significant and timely improvements in Army aircraft operational R&M characteristics. Emphasis will be directed toward development of diagnostic/condition-monitoring capability, advanced R&M component design concepts, system-level R&M analysis capability, and improved testing methodology for R&M for air vehicle subsystems to reduce life cycle costs and improve reliability, maintainability, and availability.

All efforts under this project number will emphasize R&M assessment of advanced development projects such that subsequent engineering development programs will properly reflect R&M considerations. Maximum use of operational suitability (field) testing is used to gain insight into problems of reliability and maintainability.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the R&M R&D efforts as presented in the technical discussion are shown and discussed in the Resources Required section. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 and 6.3 R&M R&D efforts are shown in table RM–B. Included in the table is the ratio of the R&M efforts to the total 6.2 and 6.3 Laboratory R&D efforts.

TABLE RM–B
R&M TECHNOLOGY FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78	
6.2*	1L262209AH76-TA IV	1500	9%*
6.3	1L263209DB38	0	0%

*Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.

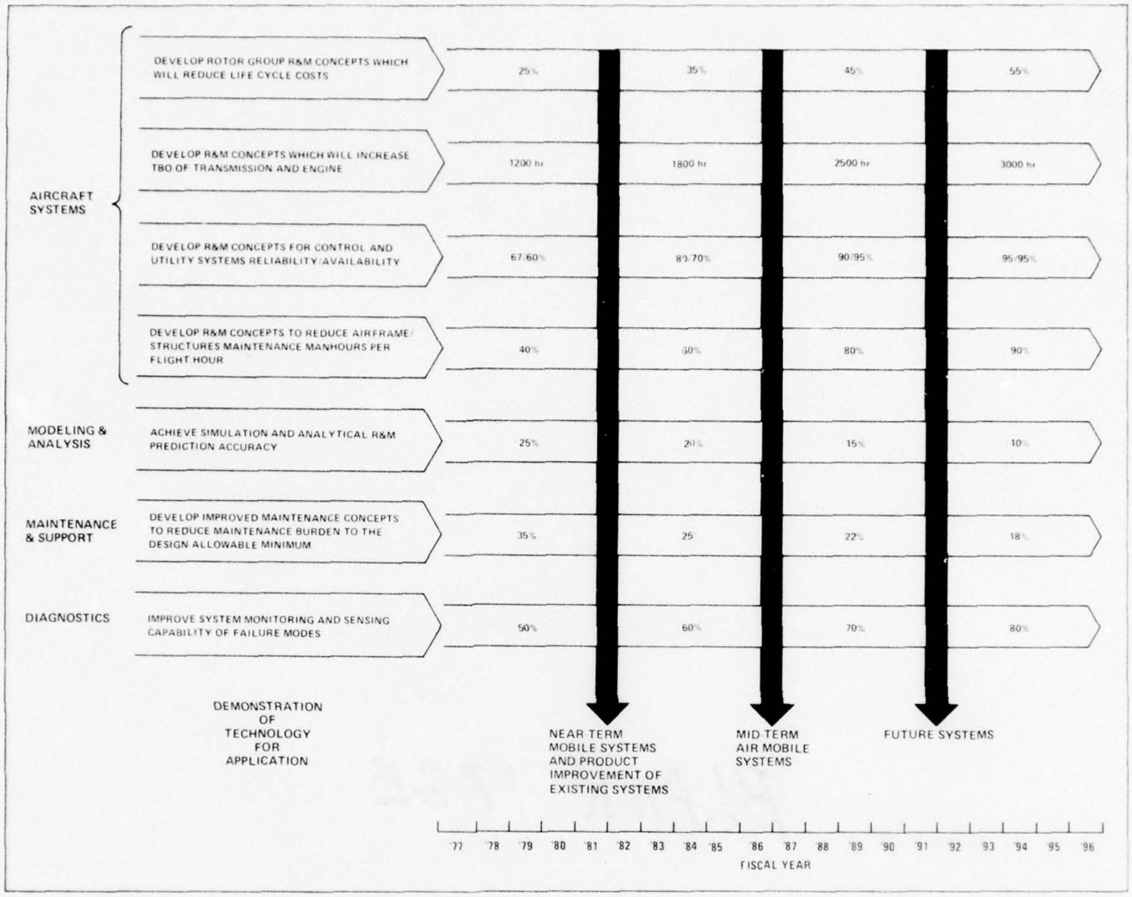


Chart RM-1. R&M achievement goals.

INTRODUCTION

Aircraft safety and survivability are described as the development and application of those techniques and concepts that allow aircraft systems and subsystems to withstand exposure to adverse outside elements or to continue to perform required functions when exposed to such conditions. These outside elements include the enemy, nature and, in some cases, the crew itself in the case of misjudgments.

The ability of an aircraft and crew to survive in combat with reasonable assurance of completing the assigned mission is known as survivability. R&D activities under this broad classification include threat analysis, reduction of detection, and ballistic protection of aircrew and aircraft. The survivability element is heavily influenced by the threat environment associated with the mission and is complemented by the design of the aircraft subsystems and by such features such as size, agility, and on-board armament. Threat analysis involves intelligence sources, synthesis to determine critical weapon characteristics, and assessment of weapons effects; the results of this analysis allow the development of potential countermeasures and effectiveness assessment. As the threat level increases, significant changes occur in the effectiveness of reduction of detection, ballistic protection, and tactics (figure SS–1). As the threat level increases, tactics plays an increasing role in providing the requisite assurance of survivability.

Safety pertains to the ability of an aircraft and its crew to survive in a noncombat environment. In this regard, safety is somewhat redundant since the need for crashworthiness and fire prevention is implicit in the need to survive combat damage. Safety R&D efforts have been divided into these basic elements: in-flight (operational) safety, in-flight and postcrash fire prevention, and structural crashworthiness.

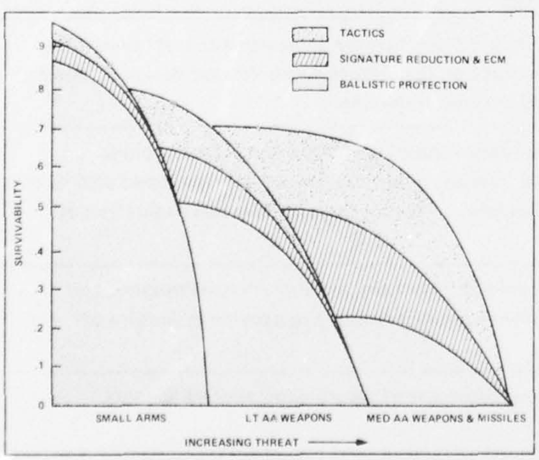


Figure SS–1. Changes in survivability methods with increasing threat.

Research and development in safety and survivability is, to a great extent, applicable to all of the Army's planned airmobile missions. The emphasis on safety and survivability depends on the mission. Because of their combat roles, AAH and AAWS, for example, have greater emphasis on combat survivability than do cargo-carrying aircraft. Safety and survivability improvements incorporated as an integral part of a new mission system must be considered in the initial stages of engineering design to achieve the most effective design for the least cost and with the least performance penalty.

Within each safety and survivability subarea, quantified achievement estimates have been established as presented in chart SS–I (located at the end of this section). Incremental achievement goals are shown for the 20-year span covered by the Plan.

The subdiscipline areas of safety and survivability discussed in this section are:

- Survivability through reduced detectability
- Survivability through aircraft and aircrew protection
- Safety
- Vulnerability analysis
- Aircraft Survivability Equipment (ASE)

TECHNOLOGICAL DISCUSSION

SURVIVABILITY THROUGH REDUCED DETECTABILITY

GENERAL

The major thrust in reducing aircraft detection (which is a form of passive countermeasure) is to formulate concepts and develop means to provide an aircraft with an inherent low detectability signature. This approach degrades or denies target acquisition by enemy weapon systems that use the aircraft signature characteristics for surveillance or guidance. Aircraft may be identified and acquired as targets by

techniques ranging from unaided visual and audible detection to highly sophisticated optical and electronic sensing.

Countermeasures against threat systems can involve either reduction of the aircraft signature, deception (where the sensors are confused by jamming or decoys), or using an efficient combination of both signature reduction (passive countermeasures) and deception (active countermeasures). Ideally, passive countermeasures are designed into the aircraft at minimum penalty. However, when the threat is postulated for a specific mission or the performance degradation is significant, these countermeasures can be made available as kits, to be used only when required. Signature reduction, which is normally broadband, is effective against a variety of weapons. Active countermeasures are generally more sophisticated and dependent on the precise characteristics of a specific guidance system or sensor. They are likely to appear as mission-oriented kits complementing passive systems on the aircraft and must incorporate flexibility to be capable of defeating the variety of sensor modifications for a given weapon system.

The subtechnical areas discussed under this subdiscipline are defined in table SS–A.

RADAR REFLECTIVITY

Significant reductions in broadband, low-penalty, radar cross section (RCS) can be made in the design of aircraft by shaping and by carefully applying radar-absorbent materials. Recent applications of absorbent material to observation helicopters have shown a significant reduction in RCS. Further evaluation of materials and improved application techniques are required before operational use. Shaping studies have shown basic that reduction in RCS is possible and further analysis is being performed to define structural tradeoffs; that is, weight, cost, etc. Emphasis is being placed on reducing the RCS of rotor blades (both main and tail) to counter the threat of moving target indicator mode of search and tracking-type radar systems. Improvements in concepts and application of RCS reduction to dynamic components are under development. The trend curve in figure SS–2 shows the potential reduction in RCS of rotary-wing aircraft with respect to frontal exposure.

The survivability contribution of RCS reduction against the current known threat has been assessed for the case in which tactics call for nap-of-the-earth flying; this assessment indicates that a significant capability for increasing survivability is possible. Further analysis and experimental hardware evaluation of

TABLE SS–A
SUBTECHNICAL AREAS – REDUCED DETECTABILITY SUBDISCIPLINE

RADAR	• Pertains to definition of radar reflectivity (echo) of aircraft systems. Selection of echo reduction in relation to active systems (jammers) is studied, and is dependent on threat system and deployment.
INFRARED	• Pertains to definition of IR emissions from turbine engine and aircraft systems. • Development and selection of reduction techniques and hardware design is based on threats analyzed for required counter-measures.
VISUAL	• Pertains to the investigation and definition of aircraft features that provide significant visual detection cues. Concepts and techniques are developed and field evaluated. NOE mission profiles form a baseline for effectiveness evaluation of detection reduction.
LASER	• Pertains to the evaluation of developing laser threats and the development and evaluation of material application to aircraft systems to provide reduction of laser damage and detection.
ACOUSTIC	• Pertains to the definition and measurement of rotary wing aircraft acoustic signature. • Analysis of noise propagation, noise reduction, and trajectory management are conducted to evaluate survivability effects.

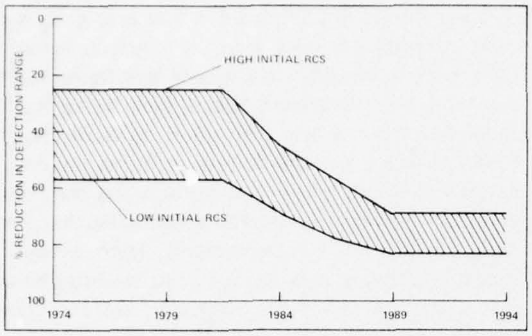


Figure SS–2. Radar cross section reduction trend – frontal aspects.

this tactical mode is in process. The development of prediction techniques for helicopter RCS is under way and will require continued comparison with measured data for refinement and increase of confidence levels. Continuing analysis of existing and anticipated threat radar systems is required to determine the most effective approaches for countermeasures.

RCS reduction alone cannot provide complete protection against radar-controlled weapons or surveillance. It can provide (at minimum cost in space, weight, and power effectiveness) broadband reductions in radar return, thus decreasing the range at which the aircraft can be detected or acquired as a target and significantly reducing the space, weight, power, and complexity of complementary active electronic countermeasures where required. To provide the most efficient package against known and anticipated threats, a continuing effort is required to determine target levels of passive and active countermeasures for each aircraft system.

INFRARED EMISSIONS

Exhaust Plume Radiation. Initial investigations of turboshaft exhaust plume radiation characteristics, methods for prediction of radiation levels, and methods or techniques for reduction of plume radiation have been completed. Experimental plume suppression hardware has been designed, fabricated, and field tested. Further efforts, as outlined below, are required:

- Evaluation of reduction concept hardware.
- Investigation of rotor downwash and slipstream interaction with exhaust plume flow field conditions.
- Assessment of the developed plume prediction program for accuracy against a variety of measurement data to improve confidence levels.

Hot Metal Radiation. Emphasis has been placed on cooling and shielding hot parts because these are the major contributors of IR radiation in the bandwidths of known threat missiles. The use of air film and air film-convection cooling have been evaluated on curved wall centerbody shielding IR suppressors. The curved wall diffuser aerodynamic losses have been reduced to less than 1 percent and diffusers can be designed to match the pressure recovery of the engine to which infrared suppression is applied. Coatings for application to IR suppressor surfaces were developed to provide a range of emissivity levels while being subjected to the turbine engine exhaust environment. A continuing emphasis, as technology changes, is required in the following areas:

- Apply (scale up or down) existing IR suppression technology to inventory aircraft.
- Improved definition of threat weapons characteristics to asses properly countermeasures capability.
- Determine target levels of passive and active countermeasures for each system to provide the most efficient package.
- Update infrared measurements and analysis procedures.
- Improve operational analysis procedures and experimental verification techniques.

Effectiveness goals for IR passive countermeasures against present and anticipated IR-seeking missiles are shown in chart SS–I.

VISUAL DETECTION

In general, visual countermeasures against an optical tracker or weapon aid are rather limited because both devices operate on contrast difference. Trackers can either be mechanically scanned optics or combinations of electronics and optics. Target characteristics that can be used for tracking are: contrast with background, point-to-point contrast across the target, and active lights on the target.

Visual detection investigations show that the mechanism of detection of helicopters at ranges up to about 1.5 km by the unaided eye is primarily dependent on:

- Sound
- Motion
- Color
- Size

Any one of these characteristics is sufficient for detection. The important visual detection cues in the 1.5 to 3 km range are:

- Canopy sun reflections
- Rotor flicker
- Fuselage shape
- Motion
- Contrast

Statistically significant differences in probability of detection or detection distance occurred when certain countermeasures were used. Listed in order, with the most effective first, they are:

- Flat paneled canopy
- Open structure tubular tail boom
- Color

Greater reductions in detection takes place when the above countermeasures are used in combination. From 1.5 to 2.5 km, contrast is a significant visual detection characteristic. Pattern painting has no beneficial effect. At ranges greater than 2.5 km, color and pattern have an insignificant influence on visual detection, provided they are not in sharp contrast to the background. The distance between the aircraft and the background is very important, especially in lower visibility conditions. The helicopter is easier to detect as it moves farther away from the background. Further investigations in defining combinations of low-glint canopy designs and reduction of internal cockpit glint are in process.

LASER DETECTION

The following types of laser systems are presently in development or operationally in use:

- Rangefinders
- Beam riders
- Designators
- High-energy beams (material damage)

Laser threats can be placed in two general classes, each requiring its own form of countermeasures: those laser threats that rely on one-way transmission of energy to a vulnerable target (direct attack); and those laser threats that rely upon reflected energy from the target for operation (rangefinders and designators). Concepts of special coatings and absorbers are under investigation to reduce the vulberability of Army helicopters to direct-attack laser weapons. Aerosol scattering concepts are being investigated to reduce detectability from other laser aided weapon systems and potential for visual, IR, and radar countermeasures.

AURAL DETECTION

Efforts are being directed toward increased understanding of acoustic phenomena and the influences of various acoustic signature levels on aircraft survivability. The worth of attaining reduced aural detection distance through reduced helicopter noise levels must ultimately be assessed by a survivability payoff. Conversely, a survivability level can establish the allowable aircraft noise levels. Recent studies of visual detection show a marked decrease in visual acquisition ranges when the aural cue is missing. The thrust of aircraft noise studies is directed toward the helicopter due to the Army's heavy dependence on rotary-winged aircraft.

Noise reduction technology can reduce helicopter detection distances, but can have significant effect on aircraft performance. Consequently, accurate and realistic acoustic detection criteria are essential. Investigations have been completed which equate noise reduction with survivability and use the aircraft aural detection "footprint" to alert weapons and compute kill.

Field evaluations and analyses have addressed the propagation of aircraft noise and its effects on listening troops. Flight tests have investigated pilot-influenced noise control (trajectory management). Future effort will further develop refinements of studies in transmission path technology, subjective factors, mission analysis, and weapon capabilities.

TOPICS SUMMARY

The various areas of research pertaining to survivability through reduced detectability that are required to develop this technology are summarized below. Should each of the areas be adopted as an element of

a unified research program, the objective goals indicated in chart SS–I could be achieved.

Radar Reflectivity

- Investigate new concepts of radar attenuating material for application to primary structure: rotor blades, fuselage, etc.
- Develop model, component and full-scale testing of RAM to evaluate application techniques, shaping and cross-section reduction of radar signature.
- Conduct coordination studies to determine the relative feasibility of fixed RAM versus addition of active ECM.
- Design, fabricate, and test advanced concepts low radar cross section to provide off-the-shelf technology for new mission systems.
- Conduct investigations to evaluate the effects of shaping to reduce RCS on helicopter fuselage weights.

Infrared Emissions

- Integrate IR suppression concepts and hardware technology into development of turboshaft engines.
- Conduct analytical and experimental investigations to determine cross flow exhaust plume interactions and radiation reduction effects.
- Investigate inherent cycle characteristics of turboshaft engines with IR signature.
- Develop analysis and design guide for application of IR suppression technology.
- Design, test, and verify conceptual hardware systems to minimize IR emission.

Visual and Laser Detection

- Conduct investigations to evaluate effective countermeasures against visual, laser/electro-optical directed weapons and high-energy lasers.
- Investigate aerosol scattering applications for optical countermeasure systems to determine the optimum systems for satisfying mission needs.
- Develop optical and laser countermeasure design concepts for application to new mission systems and inventory retrofit.

Aural Detection

- Develop detectibility criteria and conduct detailed analyses of operational conditions to determine initial detection levels and resulting survivability.
- Conduct survivability analyses to balance value of reduced acoustic detectability against change in aircraft performance.
- Conduct flight evaluation of Army aircraft trajectory management to determine quiet modes.

SURVIVABILITY THROUGH AIRCRAFT AND AIRCREW PROTECTION

GENERAL

This area includes the research and development of protective measures for Army aircraft and aircrews against ballistic ammunition and antiaircraft fire by application of lightweight armor materials and design techniques derived through research investigations.

TECHNICAL DISCUSSION

Vulnerability reduction technology is intended to increase Army aircraft survivability by minimizing the consequences of damage caused by a projectile hit. It includes reducing probability of attrition (crash), forced landing, mission abort, and personnel casualties as well as reducing downtime for damage repair. Significant projectile threats include all known explosive projectiles ranging from those launched from infantry rifles to automatic cannon, contact-fuzed shells, and the fragmentation and blast effects of larger ballistic or guided weapons. The mechanisms of kill include fire blast penetration and all other means of failing or degrading the critical functional systems or components of aircraft including structure, fuel, flight controls, propulsion, drive trains, crew armament, mission equipment, and cargo.

Protection of Army aircraft and aircrews against ballistic ammunition and antiaircraft fire by application of lightweight materials and design techniques must include vulnerability analyses of aircraft systems and components to determine the initial protection required against advanced weapon systems and to progressively improve protective techniques.

Primarily, the basic vulnerability data are obtained from experimental testing and analysis and from

study of combat data to determine means of increasing the survivability of Army aircraft (primarily helicopters) employed in forward area operations, where they are subject to attack from a wide variety of weapons.

Secondarily, the reduction in weight of ballistic-damage tolerant materials suitable for protection of current and future aircraft and their crews are investigated. This effort includes research and development of opaque and transparent materials, composite materials and plastics, processing and fabrication methods, ballistic testing, and performance evaluations as well as obtaining armor materials design data and disseminating technical information.

The basic vulnerability data and the lightweight ballistically-tolerant aircraft materials generated above are used to formulate a third consideration: effective design criteria for aircraft and crew protection.

However, upgrading the three technologies is a continuing process. For example, the 23-mm high-explosive projectiles and other ordnance encountered in midintensity warfare are very significant threats to future airmobile operations. Current threats have been defined and considerable data exist as to the effects on aircraft of blast, thermal radiation, and electromagnetic pulse. Little work has been done, however, toward providing aircraft protection or to defining quantitative trade-off parameters. High-energy lasers could become a major threat to low-altitude airmobile operations in the 1980s. Limited activity is under way for detecting laser sources and for protecting crew and critical areas with not only ballistic-resistant and ballistic-tolerant design concepts, but also with laser-resistant material as well.

TOPICS SUMMARY

The various areas of research required to develop technology for reduced vulnerability to combat damage are summarized below. Should each of the areas be adopted as an element of a unified research program, the objective goals indicated in chart SS–I could be achieved.

Fuel Systems

- Establish the feasibility of a membrane nitrogen-inerting system for helicopter fuel cells.
- Conduct ballistic tests to establish tolerance of Army helicopter fuel cells to internal pressures generated by an ullage explosion.
- Conduct system studies of methods for detection of fuel vapors and fuel system punctures, including automatic jettison.
- Conduct vulnerability studies of fuel and fuel/air vapors in tank ullage and voids to assess hazards.
- Conduct studies to predict ram pressure in fuels and methods of attenuation.
- Design, fabricate and test fuel tank materials for resistance to ballistic damage and determine internal tank explosive pressures.
- Develop design criteria for ballistic protection of all systems.
- Conduct research on blast effects from high-explosive projectiles.
- Design, fabricate, and flight test prototype fuel systems for system compatibility.
- Conduct ballistic tests on prototype fuel system to substantiate suitability for mission systems.
- Continue studies and tests to evaluate new threat levels and effects on all mission subsystems and overall mission performance.

Flight Control Systems

- Develop composite materials (plastics, metals, fibrous hybrid combinations) that can be economically fabricated into low cost and lightweight control components that tolerate projectile impact and subsequent damage. Fire resistance and non-toxicity material characteristics are also to be considered.
- Develop survivable servoactuators (ballistic-damage tolerant, jam-proof, redundant types) with little or no weight penalty that can withstand projectile impact and damage with no serious effect on continued flight.
- Design, fabricate, and test ballistic-damage tolerant control systems under static and dynamic loads with emphasis on simplicity of design, low cost, low weight, reliability, repeatability of characteristics, and maintenance-free under adverse environmental conditions.

- Design and flight test practical and cost effective survivable control systems (ballistic-damage tolerant, fly-by-wire, redundant, or combinations of such types) configured for specific missions or threats.

Dynamic Systems

- Develop materials and coatings suitable for gears and bearings that require minimal lubrication and minimal cooling to operate for a minimum of 2 hr under reduced loads but capable of sustaining reduced flight power.
- Design, fabricate, and test an integrated tail rotor servo power module.
- Design, fabricate, and test a ballistic damage tolerant tail rotor severance system.
- Develop lightweight, high-strength composites, specially suited to accommodate ballistic damage, for application to rotor system.
- Design, fabricate, and laboratory test transmission systems that can accommodate ballistic damage of specified threat level.
- Provide off-the-shelf technology for engineering design of high survivable transmission systems.

Aircrew Stations

- Conduct wound assessment studies of the human body to determine transient depression tolerance.
- Develop lightweight materials suitable for crew seats to defeat fragments and debris with specific head and neck protection.
- Develop low-density, hard materials for integral armor applications.
- Develop new, low cost, low-density transparent materials that can defeat specified threats with minimum spall and debris.
- Design, fabricate, and test armor systems to provide off-the-shelf technology for new mission systems.
- Design and fabricate ballistic test integral armor shells.

Tail Boom Vulnerability

- Conduct in-house ballistic testing of tail booms to determine failure modes.
- Fabricate and test prototype tail boom modifications to evaluate effectiveness against high-explosive projectiles.
- Conduct research on blast effects from high-explosive projectiles on tail rotor drive shaft and control systems.
- Develop design criteria for ballistic protection of tail booms, drive systems, and control systems.

Other

- Develop structural criteria and techniques for aircraft and aircrew protection against nuclear weapons and high-energy sources.

SAFETY

OPERATIONAL FLIGHT SAFETY

General. Operational safety is interrelated with reliability (as well as training and human factors), because operational safety depends on the continued functioning of components and subsystems during flight. In addition to the identification of critical subsystems and components for improved in-flight reliability, emphasis must be placed on devices and techniques to provide crew information that will prevent the increasing incidence of accidents due to the incorrect assessment of conditions.

Operational Hazards. Analysis of aircraft accident statistical data reveals that a significant number of accidents are attributable to operational hazards many of which could be eliminated or minimized through the application of sound design practices during the early design stage of aircraft weapons systems.

In the past the Army has conducted a very limited effort in this area because of the lack of funds; however, certain operational hazards that cause or contribute to Army aircraft accidents have been identified. One effort needed to reduce operational hazards is the design, development, and evaluation of a helicopter gross weight and center-of-gravity indicator system applicable to Army utility and cargo helicopters. The development and qualification of this system could provide the crews of Army helicopters with an accurate and reliable indication of aircraft gross weight and center of gravity location prior to takeoff. Other problems, associated with NOE

flight, include tail rotor and main blade strikes, which often are attributed to pilot error; however, strike-tolerant blades could prevent incidents from becoming major accidents, with attendent injuries and fatalities. In other areas, the pilot's ability to cope with unusual conditions is often affected by over-gross loading, power limitations, control limitations, and lift margins usually initiated by operations in off-design circumstances.

Emergency Escape. Many fatalities and injuries occur to aircrews because they cannot escape from an aircraft in an inflight emergency. A review of operational experience and aircraft accident statistical data clearly indicates that a large percentage of aircrew fatalities could have been prevented through the use of an adequate escape system during inflight fire, midair collision, etc. Emergency crew escape techniques and capabilities for aeronautical vehicles exist in the form of bailout parachutes, ejection seats, encapsulated seats, and escape capsules. Ejection and extraction-type escape system components developed for conventional fixed-wing aircraft are available for rotary-wing aircraft; however, new techniques may have to be developed for ejection from rotary-wing aircraft. Conceptual studies and limited experimental testing have also been conducted on sidewise and L-shaped trajectories for extraction of aircrewmen from helicopters through the use of propellant-actuated devices. Application of conventional upward ejection (or extraction) techniques is not yet considered feasible until the undefined effects of rotor disposition have been established. The various techniques for crew egress from rotary-wing aircraft are currently considered as high risk until the concepts proposed have been subjected to experimental verification. The nap-of-the-earth operational concept further complicates the technological development by placing more severe operational requirements (low altitude, nearly zero reaction time, aircraft attitude, etc.) on the system while increasing the need for such a system.

An exploratory development program can be implemented that will consider the extreme conditions under which a VTOL emergency crew escape system must function. This program would include the formation of concepts and techniques involving trajectory control for an escape system; aircraft attitude reaction horizon seekers; explosive sequence control systems for multimode operation; emergency sensors; and rapid-action, fully automatic escape system initiation and operation.

Flight Safety Plan. The objectives of the operational Flight Safety Plan are to develop concepts and criteria for the design of equipment and safety devices that, when retrofitted to current aircraft or incorporated into the design of developing or future aircraft weapon systems will reduce or eliminate the incidence of Army aircraft accidents caused by the operational hazards to which these aircraft are exposed.

A continuing analysis can be conducted to identify and isolate, on a system/subsystem basis, critical design deficiencies, techniques, and operational hazards that frequently cause or contribute to Army aircraft accidents. Analytical techniques can be developed to predict and isolate potential safety hazards early in the life-cycle development of future Army aircraft weapon systems. The design deficiencies identified through such an analysis can be used to formulate specific development needs which should become a part of the system safety program.

CRASHWORTHINESS

General. Crashworthiness involves the development of techniques for minimizing the crash effects on crew and passengers and reducing the high replacement costs of aircraft and components. Crashworthiness R&D seeks to eliminate or reduce crash hazards (other than post-crash fire) that cause occupant injury during aircraft crashes. A major facet of crashworthiness is structural crashworthiness (i.e., the ability of the aircraft structure to maintain a protective shell around occupants during a crash and to minimize accelerations applied to occupiable portions of the aircraft during impact). Other facets of crashworthiness include occupant retention systems, delethalization of cabin and cockpit volumes, post-crash emergency ingress/egress provisions, and retention of ancillary equipment carried on-board the aircraft.

During the early and middle 1960s, numerous accident investigations, full-scale crash tests, and evaluations of fixed- and rotary-wing aircraft were conducted. The results verified that Army aircraft of the late 1950s and early 1960s were designed for airworthiness alone, with little or no emphasis placed on the crash survivability aspects of aircraft design. Sufficient data have been generated on crash kinematics and kinetics to permit (1) statistical definition of crash impact conditions, and (2) identification of crash hazards and design inadequacies for aircraft

designed in the 1950s and early 1960s. Accident analysis for that period revealed that approximately 95 percent of the injuries and 50 percent of the fatalities in Army aircraft accidents were occurring in potentially survivable accidents; moreover, approximately 94-96 percent of all accidents were potentially survivable. This figure included post-crash fires which accounted for approximately 40 percent of the fatalities and which have essentially been eliminated by technology advances made during the early 1970s. Another 47 percent were from impact trauma, for which technology is still being generated.

Preliminary design criteria and concepts for improved aircraft crash survivability design have been established and published in USAAMRDL TR 71-22, "Crash Survival Design Guide." MIL-STD-1290AV has been published for light fixed-wing and helicopter crashworthiness.

Recent research and exploratory development efforts have resulted in significant technological advancements in the areas of load-limiting devices, crashworthy crew seats, restraint systems, and aircraft structural crashworthiness analytical techniques. It has become evident that more refined engineering criteria and designs are needed in the crash survivability areas of seats, airframe, cargo tiedown, litters, landing gear, ancillary equipment tiedown, energy absorption methods/devices, and materials before the advanced and engineering development efforts can be conducted with acceptable risk.

Crashworthiness Criteria. The objective of the crashworthiness program is to develop design criteria and optimize the design of aircraft components and items of personal equipment to the extent that present and future Army aircraft will provide the maximum protection to occupants when they are involved in an accident and will minimize the loss of lives, material, and mission performance.

Crashworthiness Goals. The quantitative measure of crashworthiness can be expressed in terms of injuries per potentially survivable accident and fatalities per potentially survivable accident. The trend goals for these ratios (figure SS–3) show that the first major reduction in both injuries and fatalities resulted from retrofit implementation of crashworthy fuel systems. The second reduction, beginning about FY80, reflects the anticipated rate with the introduction of the UTTAS and AAH, which incorporate crashworthiness criteria designed into the basic aircraft.

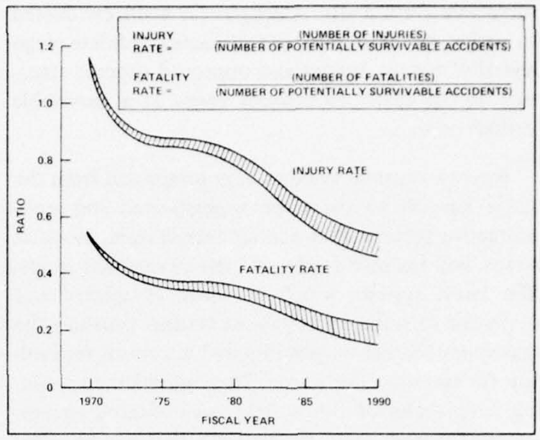


Figure SS–3. Crashworthiness improvement goal.

Technical Discussion. A continuing program can be conducted to improve the analytical tools available to the aircraft crashworthiness engineer so he can more easily and accurately determine how structures or devices will be altered when loaded dynamically to plasticity and failure. This program will include development of a three-dimensional mathematical model capable of predicting the biodynamic response and injury potential of crash impact loading of seated occupants.

The advent of the armed helicopter within the Army introduced an additional safety hazard, that of providing protection in the crash environment to those crewmen performing gunner duties. An effort has been conducted to develop design criteria and preliminary seat designs that can provide occupants with the maximum degree of protection during survivable accidents.

A program has been conducted to design, fabricate, and test prototype models of side-, aft-, and forward-facing troop seats with integral restraint systems, in accordance with a draft military specification based on USAAMRDL TR 71-22. The draft military specifications are being revised, and advanced development can be conducted using the best design concepts.

The restraint of cargo aboard an aircraft is very important in a survivable crash to prevent injury to crew and passengers. However, restraining devices of sufficient strength to preclude breaking or tearing in a crash are useless if the tiedown points and surrounding structure are not of sufficient strength to withstand the imposed loads. Therefore, improved structural strength is needed at critical points to withstand

survivable crash loads. A program is being conducted to design, develop, test, and evaluate candidate cargo restraint system designs and improved support structure in an effort to restrain cargo in a survivable aircraft crash.

Aircrew restraint systems have progressed from the single lap-belt to the more sophisticated and more protective systems that contain inertia reels, shoulder straps, belt tiedown straps, and lateral restraint straps. The latest system, which has been completed and subjected to static and dynamic testing, provides the maximum protection possible within current technology for systems of this type. To eliminate the remaining deficiencies of this system, an advanced aircrew restraint system can be developed that will be comfortable, lightweight, practical, and provide protection to the wearer during survivable aircraft crashes beyond the conventional belt/webbing/buckle-type systems. A troop seat restraint system study has been accomplished to produce a draft troop seat restraint system military specification as well as an experimental prototype design.

During the past 15 years, numerous crashworthy design concepts have evolved from the investigation of aircraft accidents and from the conduct of dynamic crash tests. Many of these concepts represent a radical departure from conventional design practices and verify the need for a program to demonstrate the effectiveness of the designs and to determine the feasibility of their use in future Army aircraft. A recent effort developed rotary-wing landing gear concepts and preliminary design criteria to lessen the magnitude of crash forces transferred to the occupiable area of helicopters involved in severe, but survivable, accidents; without producing failure loading on the airframe. The results can be applied to the design, fabrication, and testing of an experimental prototype landing gear for a specific aircraft; subsequently, landing gear specifications applicable to all future Army aircraft procurements can be revised. During 1969-1970, a mathematical nonlinear lumped mass model having 23 degrees of freedom was developed to simulate the response of a helicopter airframe to vertical crash loading. Current efforts can result in the development of a computerized rotary-wing aircraft model that predicts dynamic response to combined vertical and lateral loads. These efforts will be expanded to take into account all components of the typical crash pulse.

Because of recent interest in aircraft and automobile crashworthiness, numerous energy-absorbing devices have evolved; however, only limited mechanical and physical data are available pertaining to them. A continuing program will be conducted for the purpose of (1) developing energy-absorption devices to meet the needs of crashworthy subsystems and systems, (2) evaluating, through analysis and testing, the crashworthiness potential/disadvantages of materials (particularly composite materials) and energy absorbers, and (3) evaluating the capability of energy-absorbing devices to function reliably in the Army aviation environment. Emphasis will be placed on developing higher energy absorption capabilities, lower weight, and improved R&M characteristics. Also, potential crashworthiness applications for air bag devices will be investigated.

Periodic revision (approximately biannually) of the "Crash Survival Design Guide" can be continued to reflect not only the results of this program but also structural crashworthiness programs conducted by industry and by other Government agencies.

Primary goals of this task are to evaluate new aircraft systems and to conduct design studies to determine efficient ways of coordinating the various crashworthiness design techniques. Because of the numerous new Army aircraft systems currently planned, the need is essential technical support in the form of criteria that interface with other disciplines, proposal evaluation, crashworthy analytical evaluation, and dynamic testing of the systems as test vehicles become available.

POSTCRASH HAZARDS

Fire Prevention. Fire prevention involves the development of techniques for prevention of the incidence and propagation of fire after impact. The aircraft fire prevention program is to develop procedures and techniques that will minimize potential ignition sources, limit the propagation of fires that do occur, and provide fuel and flammable fluid containment systems that are optimized from the standpoint of crashworthiness.

For the past several years, a comprehensive theoretical and dynamic test program has been conducted to develop new concepts and criteria to improve the overall crash survivability of Army aircraft. Based on the results of these research efforts, crashworthy fuel systems have been designed, fabricated, and retrofitted on the majority of existing Army aircraft. All future Army aircraft will contain a crashworthy fuel system.

Inflight/Postflight Fires. Although Army aircraft accident statistical data indicate that the majority of aircraft fires result from crash impacts, the frequency of occurrence and significance of inflight fires are of such magnitude as to warrant a program to identify the primary causes and factors, and to develop and qualify a system applicable to the detection and automatic suppression of inflight fires. The UH–1, AH–1G, and CH–47 were investigated to determine the major causes and contributing factors of inflight fires in the combat and noncombat environment, and a breadboard model of a detection and suppression system was fabricated and tested. Safety benefits will accrue through system improvements such as these, but the safety characteristics of the fuel itself must be improved before postcrash fires are completely eliminated. Research efforts have demonstrated that some types of modified fuels are generally compatible with current aircraft fuel system components. Fire-resistant hydraulic fluid has also been developed and is being evaluated in Army aircraft.

Quantitative measurement for aircraft fire prevention and reduction in injuries/fatalities is expressed in two ways: in the percent probability of an inflight fire when the fuel system is impacted by an incendiary round; and in the suppression of fire onset following a crash for a period of time (normally expressed in seconds) allowing occupants safe egress. Trend goals for these factors are shown in figures SS–4 and SS–5.

The installation of the crashworthy fuel system on currently operational Army aircraft has reduced the incidence of post-crash fire and reduced the number of thermal fatalities sustained in survivable accidents. For a 6-year period (1970-1976) accidents for aircraft equipped with crashworthy fuel systems resulted in only 1 thermal fatality, 5 thermal injuries, and 34 fires which were of slow propagation. The crashworthy fuel system currently being installed pertains only to the containment of the fuel and does not provide containment of the oil and hydraulic system (which is further complicated by higher system pressures). The development of a crashworthy flammable-fluids system and an ignition control system will reduce the incidence of post-crash fire; however, before fires are completely eliminated, the safety characteristics of all flammable fluids will have to be improved.

Post-crash Emergency Egress. In view of the success of the crashworthy fuel system in the prevention of post-crash fires, other post-crash hazards that injure or kill occupants of Army aircraft following what would otherwise be a survivable accident should be considered during the design of future Army aircraft. An R&D program could provide design criteria and military specification revisions that would increase survivability of aircraft occupants when subjected to such hazards as exposure, drowning, and slow propagating fires; this increased survivability would be achieved by improved egress passages, escape procedures, and access openings.

TOPICS SUMMARY

The various areas of safety research that are required to develop this technology are summarized below. Should each of the areas be adopted as an element of a unified research program, the objective goals indicated in chart SS–I could be achieved.

Operational Flight Safety

- Conduct studies to determine maximum tolerance to loads on the human body.
- Conduct energy attenuation studies on deformable materials.
- Conduct studies of methods for egress from V/STOL aircraft in flight and design, fabricate and laboratory test subsystems of candidate escape concepts.

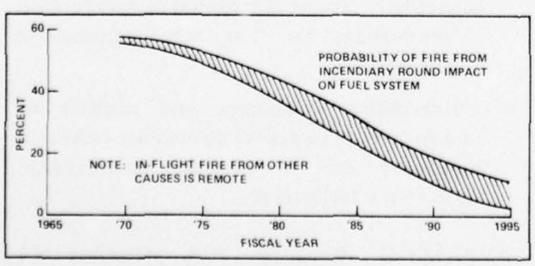


Figure SS–4. In-flight fire prevention improvement goal.

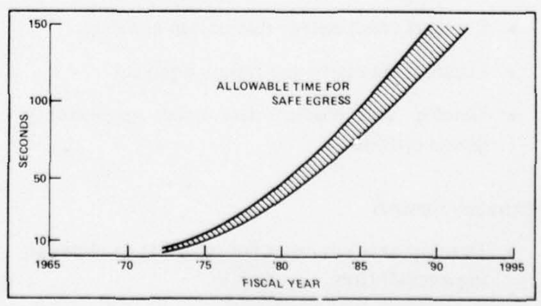


Figure SS–5. Postcrash fire protection improvement goal.

- Conduct studies of candidate transducers for application to lift margin systems and develop inflight measurement systems for lift margin parameters: engine power, atmospheric density, gross weight, center of gravity.
- Design, fabricate and laboratory test lift margin systems.
- Study terrain avoidance systems specially suited to avoidance of wires, trees, etc., in flight and establish criteria for design of avoidance systems for in-flight operation. Also increase the tolerance of the helicopter to various types of strikes.
- Conduct a study of revetments for improved design and location to minimize taxi accident.
- Continue development of criteria for flight safety based on a study of operational safety hazards.
- Investigate new vehicle concepts that improve safety through elimination of some components that have a history of causing mishaps (i.e., tail rotor).
- Improve operational safety through the corrective action process would be greatly enhanced by a crash data recorder that would accurately describe causes and provide a basis for establishment of more precise guidelines for design of survivable aircraft and life support equipment.

Crashworthiness

- Collect and analyze aircraft accident data to identify design deficiencies.
- Develop analytical models representative of aircraft dynamics during actual crash conditions.
- Develop the potential of composite materials for crash attenuation.
- Conduct crash-energy dissipation analyses.
- Conduct plasticity and failure analyses.
- Develop and publish new crash survivability design criteria.

Postcrash Hazards

- Develop new concepts for reducing or eliminating aircraft fires.
- Establish new ways of eliminating potential ignition sources (electric wires, hot metal, etc.).
- Develop sensors, actuators, and inerting devices that will serve as elements of an ignition source control system.
- Determine toxicity and smoke concentration of fire-retardant materials.
- Test and evaluate promising fire-retardant materials under aircraft environmental conditions.
- Determine by data studies and literature search the level of fire hazard from all flammable fluids and potential containment systems.
- Design, fabricate, and test fluid containment systems and verify improved crashworthiness.
- Determine capability of current fuel system components to accommodate modified low-ignition fuels.
- Conduct engine tests to determine influence of modified fuels on performance.
- Establish design criteria for increased survivability of accident occupants from postcrash conditions.

VULNERABILITY ANALYSIS

GENERAL

The Aviation Systems Command Vulnerability Analysis Team (VAT) was established pursuant to AMCR 70-53. The principal objective of VAT is to support the Army Target Vulnerability and Vulnerability Reduction Program. This objective is implemented through:

- An in-house capability for vulnerability and signature assessment of developmental and operational aircraft systems and recommendations for improving these characteristics when appropriate.
- Updating and improving vulnerability/survivability criteria as reflected in Aeronautical Design Standard No. 11 and other requirements documents.
- Vulnerability evaluations and analysis of foreign aircraft to assess vulnerability reduction measures and to compare vulnerability/survivability technology.

AVRADCOM Regulation 70-6 prescribes the policy and procedures for vulnerability analysis support by the Team. The flow of support requests by

AVRADCOM elements and Project Managers is shown on figure SS–6.

Since its inception, VAT has been trained in the methods of vulnerability analysis and has participated in the selection process of the UTTAS and AAH developmental aircraft and has conducted baseline or updated vulnerability estimates of several current fleet aircraft. In addition to conducting analyses to establish the degree of vulnerability of aircraft to a specified threat, further in-depth analysis of the vulnerability data produces information of value for a number of uses (see chart SS–II). An illustration of the information that results from this type of an analysis is shown in chart SS–III. This analysis identifies the aircraft components that are significant contributors to vulnerability, regardless of the type (or size) of the aircraft on which they are used. The information provides a firm basis for R&D efforts to reduce the inherent vulnerability of these items, or develop other acceptable ballistic protection measures under the Vulnerability Reduction Program.

TOPICS SUMMARY

The various areas of vulnerability analysis required to establish base line data for new aircraft systems design and to identify survivability improvements for current systems are summarized below. Should these areas be adopted as an element of the unified research program, the objective goals indicated in chart SS–I could be achieved.

Vulnerability Analysis

- Develop/assemble vulnerability analysis methodologies, programs and techniques.

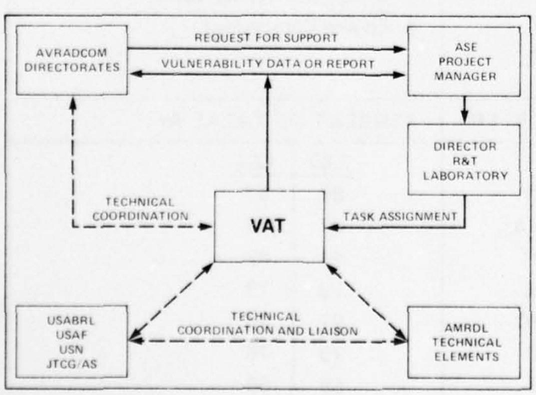


Figure SS–6. AVRADCOM vulnerability analysis support flow chart.

- Conduct analysis of current and developmental aircraft systems to determine levels of vulnerability and establish a vulnerability index for each aircraft versus threat weapons.
- Identify the major vulnerability contributors of each aircraft system and suggest design changes for improvement.

AIRCRAFT SURVIVABILITY EQUIPMENT

GENERAL

The Project Manager for Aircraft Survivability Equipment (ASE) is assigned the mission of providing self-protection for the current Army aircraft fleet on the modern battlefield; contingency protection equipment and plans as required; vulnerability analysis and development of survivability techniques and equipment for aircraft system managers; and a feasible technical data base within the DARCOM to interface with future aircraft development programs.

ASE are categorized into four technological areas:

- Radar
- Infrared
- Optical/electro-optical
- Vulnerability reduction

The first three areas describe specific frequency domains in which ASE function to defeat air defense weapons systems. Vulnerability reduction (VR) describes ASE features designed to increase aircraft tolerance to air defense weapons which cannot be completely negated by ASE in the other three areas.

The radar, infrared, and optical technological areas can be subdivided into categories of equipment based on techniques used to reduce or deny the use of electromagnetic radiation by air defense systems, that is, signature reduction, threat warning, and active response. Figure SS–7 illustrates the relationship between ASE technological areas and threat weapon fire control modes.

Signature reduction reduces the level of electromagnetic radiation emitted by or reflected from the aircraft. Threat warning ASE are employed to alert aircrew members that a fire control system is acquiring or tracking/homing in on the aircraft, and/or initiate an active response measure. Active responses are employed to confuse, jam, or decoy fire control

AIRCRAFT VULNERABILITY ANALYSIS PRODUCES	
VULNERABLE AREA (Av) DATA FOR AIRCRAFT VS: • Threat and Impact Velocity • Attack Direction • Type of Kill • Flight Condition	PRIMARY USES OF Av DATA • Selection of Aircraft • Aircraft Survivability Studies • AA Weapon Development • Aircraft Employment Doctrine
ANALYSIS OF Av DATA PRODUCES • Identification of Major Av Contributors • Component/Subsystem Damage Probability • Comparative Av of Component Design and Subsystem Configurations • Vulnerability Sensitivity to Threats, Attack Directions, and Flight Conditions	USE OF ANALYSIS RESULTS • Aircraft Vulnerability Reduction (VR) Program • Design Inputs to Reduce Av of New Aircraft • Inputs to VR and R&M R&D Programs • Inputs to PIP/ECP Actions • Aircraft Tactical Employment • Logistics and Support Planning

Figure SS–7. Relationship of ASE to fire control process.

systems that have locked on and are tracking the aircraft.

Vulnerability reduction features are specifically designed to increase the capability of the aircraft to withstand hits from ballistic projectiles and fragments from high explosive projectiles. The extent to which VR can be incorporated into an aircraft system may not be in direct proportion to the severity of the threat from ballistic projectiles since constraints of aircraft performance and cost may prohibit the application of certain VR features. The air defense threat and categories of ASE targeted against the threat are shown in figure SS–8.

ASE DEVELOPMENT PROGRAM

The ASE program must maintain a technology level responsive to changes in capabilities of enemy threat weapons and to changes made possible by state-of-the-art advances. Ideally, Army aircraft would be equipped with effective survivability equipment for immediate deployment against any hostile air defense force. However, the threat intelligence required to provide effective countermeasures is often not available until enemy weapons are committed to battle, compromised, and exploited. Thus, to ensure a high probability that ASE technology will be available when required and to minimize operational risk in the employment of ASE, it may be necessary to concurrently develop several ASE which are considered as alternative approaches to defeating a particular threat or threat class (e.g., infrared jammers and flare decoy/missile detector systems).

The ASE Project Manager sponsors and monitors development programs for advanced Army aircraft; provides systems analysis and consultation assistance to the AAH, ASH, and UTTAS Project Managers; and maintains state-of-the-art measurements and analysis techniques to generate and validate ASE requirements. The majority of ASE projects are presently in

ATTRITION KILL	RANK	FORCED LANDING KILL
• Main Rotor Flight Control Rods Ends	1	• Main Transmission — Lube
• Main Rotor Flight Control Rods	2	• Tail Rotor Drive Shaft
• Main Rotor Flight Control Actuators	3	• Engine Lube
• Main Rotor Flight Control Swashplate	4	• Engine Combustion Chamber
• Fuel Cells — Fuel Fire	5	• Tail Rotor Flight Control Rods
• Main Rotor Flight Control Pitch Horn	6	• Tail Rotor Flight Control Rod Ends
• Engine — Fuel Fire	7	• Fuel Lines — Leak
• Main Rotor Flight Control Bellcranks	8	• Oil Cooler/Bypass Valve
• Main Transmission — Gears & Bearings	9	• Engine Compressor
• Main Rotor Drive — Mast	10	

PERCENT OF TOTAL Av		HELICOPTER	PERCENT OF TOTAL Av	
7.62	12.7		7.62	12.7
66	58	OH-6A	86	57
100	97	OH-58A	87	88
91	85	UH-1H	84	82
85	86	UH-1N	79	78
59	59	CH-47C	97	99
97	84	AH-1G	79	76
97	85	AH-1T	58	58

Figure SS–8. Threat vs ASE.

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6.3/6.4 development phase. To ensure that future needs are met, the ASE-PM sponsors 6.2/6.3 programs conducted by the Electronic Warfare Laboratory and the Army Research and Technology Laboratories.

The development and procurement of ASE is grouped into two distinct categories:

- Aircraft modifications that constitute a change in aircraft configuration (e.g., signature reduction and vulnerability reduction).
- Black-box components and support/training equipment which either do not function as an integral/essential part of the aircraft or are not aircraft-type peculiar (e.g., IR jammer, radar warning receiver, etc.).

The diversity of current and potential threat systems and the severe size, weight, and power constraints presented by current fleet Army aircraft preclude the development of single, generic ASE systems. Countermeasure techniques are generally widely dissimilar and require development of several equipments, each addressed to countering a specific threat or threat class. The combination of ASE necessary to protect an aircraft during a particular mission is dependent on the nature of the threat weapon, its density, vulnerability of the aircraft, mission profile, and geographical area in which the mission is conducted.

Current inventory aircraft will be retrofitted with the ASE systems shown on figure SS–9. ASE for developmental aircraft will be inherent design objectives with retrofit only as required to meet future growth threat weapons. ASE will generally be designed as easy-to-install/remove modules to provide flexibility to configure aircraft for peacetime/training purposes and for combat situations based on specific mission profiles and threat environments.

AIRCRAFT SURVIVABILITY EQUIPMENT	AIRCRAFT							
	AH-1	OH-58	UH-1	CH-47	RU-21	RV-1	EH-1	OV-1
SIGNATURE REDUCTION								
• IR Suppressor	•	•	•	•	•	•	•	•
• Low Reflectance Paint	•	•	•	•	•	•	•	•
• Flat Plate Canopy	•	•						
• Optical Contrast Reduction Paint					•	•		•
THREAT WARNING								
• Radar Warning Receiver	•	•	•	•	•	•		•
• Laser Warning Receiver	•	•	•	•			•	•
• Adv Radar Warning Receiver	•	•	•	•	•	•	•	•
• Optical Warning Receiver	•	•						
• CW Radar Warning Receiver					•	•	•	•
ACTIVE RESPONSE DEVICES								
• Radar Jammer	•	•			•	•	•	•
• IR Jammer	•	•	•		•	•	•	•
• Chaff Dispenser	•	•	•		•	•	•	•
• Missile Detector/Flare Dispenser	•	•	•	•	•	•	•	•
VULNERABILITY REDUCTION	•	•	•	•				

Figure SS–9. Required ASE systems.

Where practical, control and display units will be integrated, multifunction components, for example, a single display unit capable of providing warning indication of a variety of threats. To the maximum extent possible, ASE will be common to several types of aircraft to minimize ASE effect on procurement and logistics.

Of the four ASE categories, active response devices place the most emphasis on a priori knowledge of threat systems; signature reduction and vulnerability reduction are the least dependent on specific threat intelligence and are therefore the most fundamental approaches to aircraft survivability. From a penalty and cost standpoint, signature reduction and threat warning reduce the space, weight, and power requirements of some active response devices. From a risk standpoint, ASE technology is well advanced except in the area of optical threat warning and active responses and radar signature reduction (figure SS–10). In other areas, efforts are centered on integrating ASE devices into optimally effective systems for each type aircraft.

TYPE ASE	SIGNATURE REDUCTION	THREAT DETECTION	ACTIVE RESPONSE	VULNERABILITY REDUCTION
Radar	Med-High	Low	Med	—
Infrared	Low	Medium	Low-Med	—
Optics	Low	Med-High	High	—
Ballistic	—	—	—	Low-Med

Figure SS–10. Technical risk.

TECHNOLOGY DISCUSSION

Signature Reduction. Improvement of aircraft survivability by reducing signatures will be accomplished by optimizing the effectiveness of passive measures against multiple threat emitters/sensors utilizing the infrared, visible, and microwave portions of the electromagnetic spectrum.

Infrared suppression of engine graybody (and plume) and secondary graybody emitters, such as transmissions, heat exchangers, and armament, will be accomplished to reduce threat weapon acquisition range and to reduce ERP requirements for active response devices.

Paint and coatings will be utilized to reduce solar infrared and visual reflections to the extent that this

technique does not increase the visual contrast of aircraft against normal earth and sky backgrounds.

Low glare canopies will be utilized to reduce the incidence of visual glint detection cues and specular solar infrared reflections utilized in tracking and guidance by infrared missiles.

Radar cross section reduction techniques are utilized to reduce the probability of acquisition/ detection within the effective range of radar-directed weapons, or to enhance the effectiveness range of active radar response devices.

Threat Warning. Provide initiation of active response devices and/or warning to aircrew to take evasive actions.

Missile detector systems will be utilized in conjunction with flare decoy systems to detect launch or approach of IR-guided missiles and initiate deployment of IR decoys.

Optical augmentation techniques will provide threat identification, direction, and range of optically-directed weapons systems. These devices will have sufficient sensitivity to detect optical trackers at ranges greater than the maximum effective range of the associated weapons system.

Laser warning detectors will indicate the direction of illumination of laser energy; identify the associated threat weapon; and, where possible, the mode of operation.

Radar warning receivers will indicate the direction of radar emitters and identify the associated threat weapon and operating mode. Advanced warning receivers will be capable of processing information from other sensors such as missile detectors and laser detectors.

Active Response Devices. Provide a means to deny or degrade detection, acquisition, fire control, and/or guidance information associated with air defense threat weapons. Active responses will be capable of manual and/or automatic operation in conjunction with threat warning devices.

Chaff/flare decoy dispensing systems will function either manually or automatically in conjunction with a radar warning receiver or missile detector system to defeat or degrade effectiveness of air defense weapons.

Infrared jammers, either fuel-fired or electrical, generate modulated IR energy to produce false target information to IR guided threat missiles. When employed with IR signature reduction techniques, jamming devices can provide significant protection against IR missiles.

Radar jamming equipment will be activated by self-contained receivers when aircraft are illuminated by fire direction/control radar systems. The effective envelope of the jammer will be such that protection is provided within the maximum effective range of the threat weapon system.

Optical contrast reduction techniques will degrade or deny optical detection, acquisition, and/or tracking by actively tuning the optical contrast of the aircraft into the background at ranges within the maximum effective range of the associated weapon system.

Vulnerability Reduction. Selected aircraft components will be ballistically hardened to increase aircraft survivability against 7.62-mm API, 12.7-mm API, 23-mm API, and 23-mm HE projectiles.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and system elements are presented in the Technology Introduction section of the Plan. This section applies that process to the safety and survivability discipline for the near-term time frame. The OPR is not an objective of the Plan, but is provided to show the Research and Technology Laboratories procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget. The AVRADCOM ASE effort is not included in this discussion.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the S&S discipline can be established from the near-term quantified achievement goals listed in chart SS–I. These objectives will

directly improve system performance, thereby reducing life cycle costs and improving the intrinsic value of the system in terms of saving human lives. The S&S objectives are:

- Improve survivability.
- Reduce acoustic detection.
- Reduce visual, radar, and infrared signatures.
- Reduce vulnerability to projectiles and laser radiation.
- Reduce accident rate.
- Reduce survivable accident injury and fatalities for survivable accidents.
- Decrease incendiary fire probability.
- Increase available egress time for survivable accidents.

PROGRAM PRIORITIES

General. Table SS–B presents, in a prioritized listing, the S&S technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts wh[illegible] [illegible]pport the near-term technical objectives.

Technology Subdisciplines. The S&S technology subdisciplines are represented by the major topical areas as presented in table SS–C.

Vehicle Subsystems. Vehicle subsystems, as related to S&S technology, are categorized as follows:

- Rotor systems
- Engines and fuel system
- Airframe
- Avionics
- Personal equipment

System Effectiveness. In the area of system effectiveness, the primary effect of safety and survivability technology is providing the ability of Army aircraft and crews to accomplish the combat mission for which they have been designed and trained and to survive. In addition, this technology reduces casualties associated with non-combat and combat-related accidents. In the life cycle area S&S plays a key role in development, flyaway and attrition costs.

Priorities. With reference to table SS–B, the S&S subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the safety and survivability R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 S&S technology development program.

The major thrusts in the area of safety and survivability are:

TABLE SS–B
PRIORITIZED S&S OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Detectability	I	• Rotor systems	I	• Survivability	I
• Aircraft and aircrew protection	II	• Engine and fuel system	II	• Safety	II
				• Attrition cost	III
• Safety	III	• Airframe	III	• Reliability	IV
• Vunerability Analysis	IV	• Avionics	IV	• Flyaway cost	V
		• Personal equipment	V	• Development cost	VI

TABLE SS–C
S&S SUBDISCIPLINE MAJOR TOPICAL AREAS

SUBDISCIPLINE	MAJOR TOPICAL AREA
SURVIVABILITY THROUGH REDUCED DETECTABILITY	• Aircraft may be identified and acquired as targets by a variety of techniques ranging from unaided visual and audible detection to highly sophisticated optical and electronic sensing systems. Countermeasures against these systems can involve either reduction of the aircraft signature by which it can be identified, by deception, or by using an efficient combination of the above.
SURVIVABILITY THROUGH AIRCRAFT AND AIRCREW PROTECTION	• Army aircraft are not only vulnerable to the hazards of normal flying, but are subject to direct hostile attack by enemy forces. In order to develop systems with adequate life cycle costs, it is necessary to increase the survivability of the air vehicle under attack by adding protective armor and/or combat-damage-tolerant structures.
SAFETY	• Crashworthiness must be included early in the design phase of new aircraft systems, so that concepts can be incorporated into the airframe to enhance its protection to crew, passengers, and high replacement cost components during a crash. • In-Flight Safety is concerned with the continued safe functioning of the aircraft components and systems during flight. This includes safe in-flight egress. • Analysis of aircraft accident historical data involving fixed and rotary wing aircraft reveals that the greatest number of fatalities occur in accidents involving fire. Fire prevention pertains to reducing this fire hazard and increasing allowable crew egress time.
AIRCRAFT VULNERABILITY ANALYSIS	• Vulnerability Analysis are performed to determine the relative vulnerability of aircraft vis-a-vis threats, flight conditions, and kill levels. • Further analysis of aircraft vulnerability data identifies the sub-systems and components that contribute to System Vulnerability and defines vulnerability reduction measures for application. • The aircraft vulnerability index or vulnerable area for specified threats and flight condition are used as inputs to survivability analysis and mission/cost effectiveness studies.

- Development of countermeasures to increase survivability by reduced detectability to enemy sensors of the vehicle subsystems/systems.
- Development of aircraft components/subsystems tolerance to enemy ordnance to increase survivability.
- Development of crashworthy subsystems to improve safety.

These thrusts are supported by the following rationale:

- From an assessment of the priority listing in table SS–B and the near term objectives stated above, it can be seen that survivability depends on, more than any other parameter, the detection time variation (DTV) between the aircraft and enemy threat forces. Therefore, the first priority is to reduce aircraft signatures to an acceptable level. The amount of R&D effort involved to counter the four means of detection (radar, IR, visual, aural), should be allocated according to the relationship of the amount and

effectiveness of the detection method utilized by threat forces, and the state of the art and effectiveness of Army countermeasures. The reduction of radar cross section (RCS), infrared, and visual signature should be first priority, because these are the prime means of aircraft detection used by the threat and because they give the greatest DTV advantage to the enemy. The state of the art in RCS, IR, and visual signature reduction can be advanced to reduce the DTV advantage of the enemy. With the increasing importance of terrain flying in the high threat environment, aural detection must also be emphasized and should be rated with RCS, IR, and visual signature reduction in importance. Supporting this prioritizing are the benefits to be gained in reducing enemy standoff weapons effectiveness.

- Once an exchange of fire takes place, survivability is enhanced by the aircraft's ability to absorb ballistic damage. Based on the number and type of enemy weapons and on the number of components considered critical to continued flight, R&D should be directed to enable those components to receive 7.62 mm, 12.7 mm, 14.5 mm, and 23 mm HEI projectile damage without immediate failure. Those components considered most critical are rotor systems and drive systems. Power plants, by virtue of multiple installations, provide adequate redundancy.

- Combat and operational records show that the aircrew members are a critical link in the aircraft system from a vulnerability standpoint; they are also difficult to protect. Aside from being an emotional and moral issue, the cost effective use of crew members calls for adequate protection from combat hazards.

- Safety is an important consideration in all aspects of Army aviation including non-combat as well as combat flying. Data show that large number of aircrewmen have been killed or injured by accidents. Therefore, development of technology to prevent accidents and to provide aircrew crash protection are of vital importance. Continued research in flight safety, aircraft crashworthiness and post-crash hazards reduction can improve the state of the art in the protection of aircraft occupants.

AVRADCOM PROJECTS FOR FY78 IN SAFETY AND SURVIVABILITY

INTRODUCTION

Safety and survivability technological development efforts are presently directed toward exploratory development (6.2) in such areas as: development of techniques for defeating or degrading the effect of known or potential threat weapons and target acquisition devices by aircraft signature reduction and aircraft design, reduction of weapon effectiveness, and improvement of crash survivability. All efforts are applicable to future combat aircraft development programs and provide a technological base for the development of UTTAS, AAH, ASH, and RPV.

The development efforts are conducted by the Applied Technology Laboratory, Fort Eustis, Virginia and the ASE Project Manager by either in-house efforts or by contract. Interface and coordination in areas of interest will be maintained with the user, other Army agencies, the other services (Navy and USAF), the FAA, and NASA.

DESCRIPTION OF PROJECTS

Safety and Survivability Technology. Project 1L262209AH76-TA V is an exploratory development effort to develop advanced technology and design criteria to enhance the effectiveness of Army aircraft in terms of increased survivability and flight safety. Survivability shall include the reduction of detection by IR, radar, optical, laser, and acoustic means and provide aircraft and aircrew protection against ballistic and laser threats. Flight safety shall include operational safety of aircraft and crews through increased crashworthiness of structure and crew seats, prevention of post-crash fire, elimination of in-flight hazards, and provision for emergency egress. The results of this program are applicable to retrofit of current aircraft and development of criteria for design of developmental and future aircraft.

Aircraft Survivability Concepts. Project 1H263208DB52-02 is an advanced development effort to develop and demonstrate the concept feasibility of Aircraft Survivability Equipment required for the protection of Army aircraft in a hostile air defense environment composed of radar, infrared, and optically directed weapon systems. The project includes development of prototype hardware for electromagnetic radiation suppression and ballistic hardening; development of measurement and evaluation

techniques, standards, and equipments; and conduct of test measurements and evaluations required to demonstrate concept feasibility. This project interfaces with project 1X763711D653, advanced development of active response and threat detection equipments.

Aircraft Survivability Equipment. Project 1H264209DC52-04 is an engineering development effort to develop, test, and type-classify for production, aircraft survivability equipment that demonstrated feasibility under project 1H263208DB52. This project continues the development of selected electromagnetic radiation suppression systems and ballistically hardened components, with emphasis on equipment integration for each aircraft survivability suit and associated system reliability, maintainability, availability, configuration and data management, and logistics support. This project interfaces with project 1X764711D665, engineering development of active response and threat detection equipment.

Aircraft Electronic Warfare Self-Protection Equipment. Project 1X763711D653 is an advanced development effort to develop and demonstrate the concept feasibility of Aircraft Survivability Equipment required for the protection of Army aircraft in a hostile air defense environment composed of radar, infrared, and optically-directed weapon systems. The project includes development of prototype electronic active response, threat detection, and complementing ground support equipments; development of measurement and evaluation techniques, standards and equipments; and conduct of tests, measurements, and evaluations required to demonstrate concept feasibility. This project interfaces with project 1H263208DB52-02 advanced development of suppression systems and ballistic hardening components.

Aircraft Electronic Warfare Self-Protection Systems. Project 1X764711D665 is an engineering development effort to develop, test, and type-classify for production, aircraft survivability equipment which have demonstrated feasibility under project 1X763711D653. This project continues the development of selected electronic active response, threat detection, and complementing ground support requirements, with emphasis on equipment integration for each aircraft survivability suit and associated system reliability, maintainability, availability, configuration and data management, and logistics support. This project interfaces with project 1H264209DC52-04 engineering development of suppression systems and ballistic hardening components.

Joint Survivability Investigation. Project 1H263215D079 is an advanced development effort that supports the Army portion of interservice efforts of the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) to reduce the vulnerability of aeronautical systems in a non-nuclear threat environment. The JTCG/AS was formally chartered in June, 1971 under the aegis of the Joint Army Materiel Command, Navy Materiel Command, Air Force Logistics Command, and Air Force Systems Command commanders to ensure that the latest aircraft non-nuclear survivability technology is available for incorporation into the design of future aircraft.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the S&S R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2, 6.3, and 6.4 S&S FY78 R&D effort is shown in table SS–D.

TABLE SS–D
AVRADCOM S&S TECHNOLOGY FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) OF COMMAND SCHEDULE FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78
6.2	1L262209AH-76 TA V	2218*
6.3	1H263215D079	581
6.3	1H263208DB52-02	1453
6.3	1X763711D653	2093
6.4	1H264209DC52-04	4659
6.4	1X764711D665	6355

*This represents 13% of the R & T Laboratories R&D 6.2 funds (excluding Project 1L262201DH96 Aircraft Weapons Technology funds.)

SAFETY AND
SURVIVABILITY

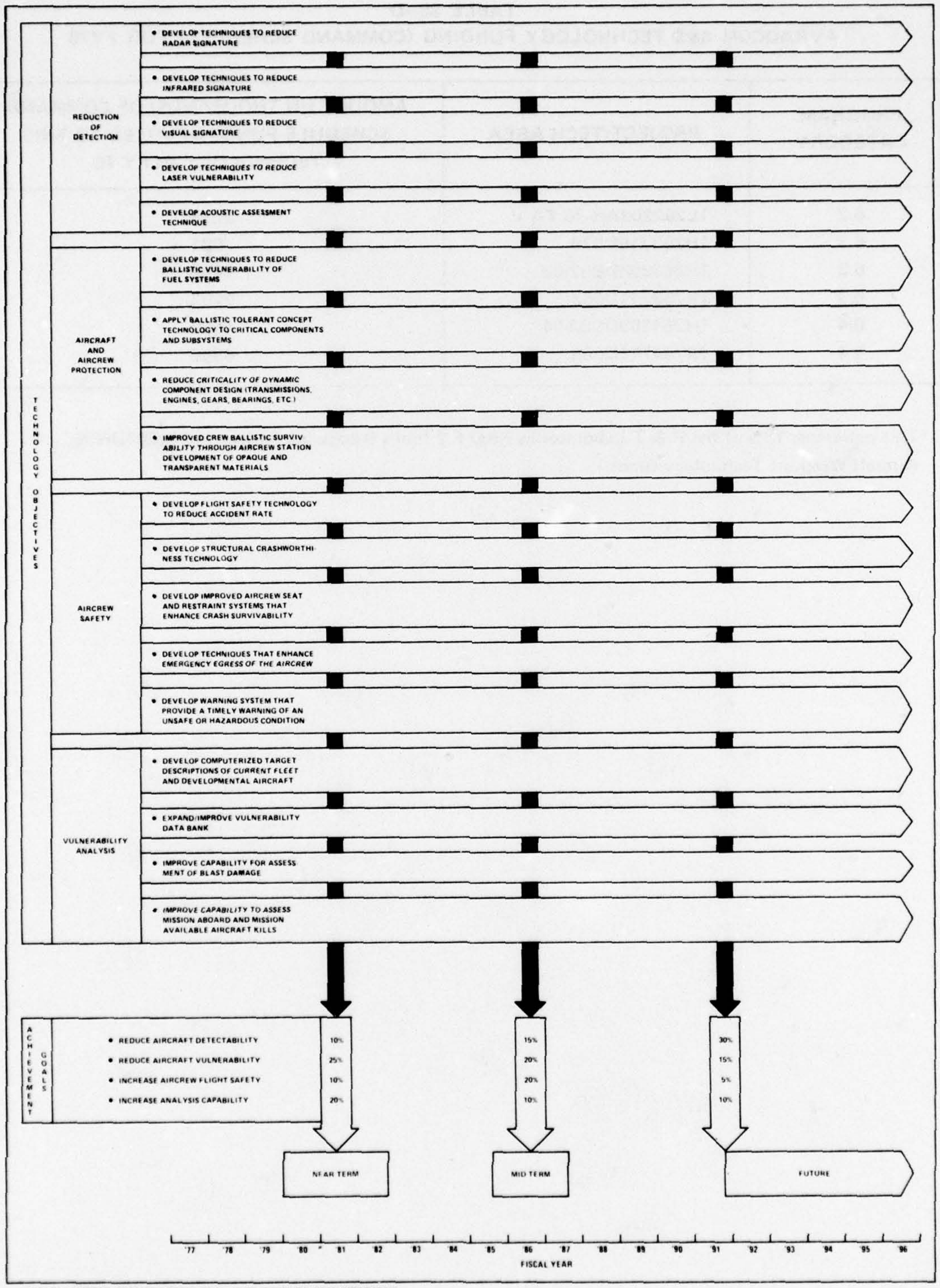
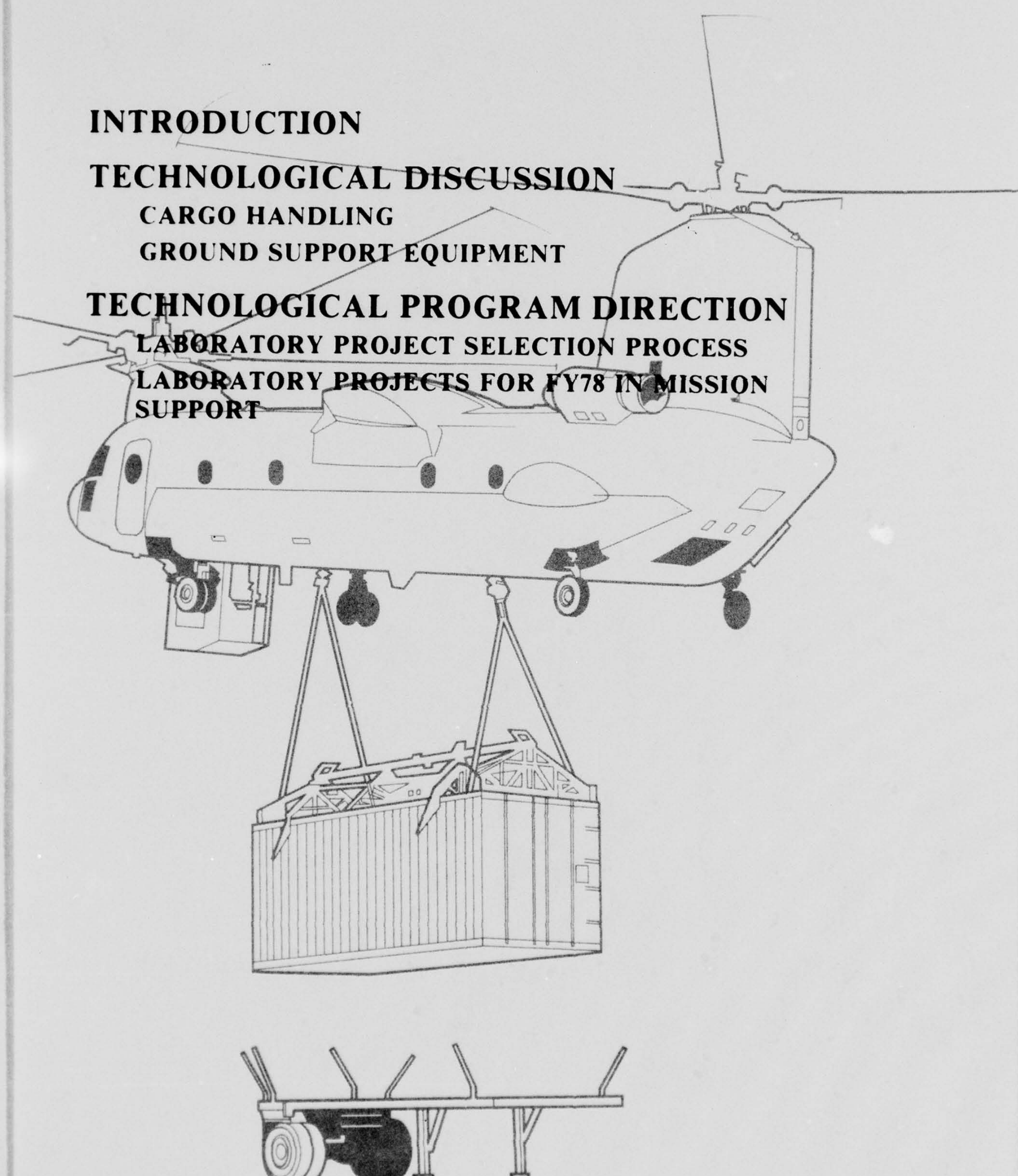


CHART SS-1 SUMMARY OF SAFETY AND SURVIVABILITY OBJECTIVES AND ACHIEVEMENT GOALS

Chart SS–1. Summary of Safety and Survivability objectives and achievement goals.



INTRODUCTION

Mission support can be generally described as those interrelated techniques and disciplines that provide Army aircraft with the capability of expeditiously performing their assigned tasks. To a significant extent, the optimal relationships among the provisions required for accomplishing these tasks determine the success or failure of the mission, the aircraft's productivity, and even its survival.

Army airmobile systems exist to assist the ground commander in conducting one or more of the functions of land combat: mobility, intelligence, firepower, combat service support, and command, control, and communications. In the contents of the Army Aviation RDT&E Plan, mission support equipment is that ancillary equipment necessary to permit the aircraft to perform a specific mission or to support the aircraft during a specific mission. This section of the Plan covers the mobility and combat service support functions, while intelligence, command, control, and communications are covered in the section on aviation electronics; firepower is covered in the aircraft weaponization section.

The effectiveness of the aircraft system is largely determined by the effectiveness of the subsystems for the mission. Thus, the ability of the aircraft to acquire and deliver loads or intelligence, or acquire and destroy targets, is the primary justification for the aircraft.

The mission subsystems have close and important interrelationships with the other subsystems of the aircraft and with other disciplines, such as aerodynamics, structures, and propulsion. As the Plan is concerned with technology development resulting in cost-effective, superior airmobile systems, the results of R&D programs in mission support systems are equally significant as the R&D results in the other disciplines.

The mission support functions discussed in this subsection and the accompanying graphs and charts describe specific goals and programs required to provide the best off-the-shelf technology to serve the present and future needs of Army airmobile systems.

The overall R&D efforts presented and discussed in the following subsections, technological discussion and technological programs, are responsive to the Science and Technology Objective Guide – FY78 (STOG-78) requirements. Program objectives have been established and displayed by text and/or charts. Where possible, quantitative achievement goals have been specified for program objectives and are keyed to near-term, mid-term, and future airmobile systems. However, any improvement could be applied to existing systems through product improvement programs.

TECHNOLOGICAL DISCUSSION

CARGO HANDLING

GENERAL

Historically, the major effort in aircraft system technology R&D has been in the basic disciplines (aerodynamics, structures, propulsion, etc.). In addition, mission systems for weapon deployment and surveillance roles have received extensive R&D activities to optimize system hardware and techniques to support these missions. However, for aircraft having primary combat support missions of delivering men, supplies, and equipment, too little emphasis has been placed on the means by which these missions can be performed efficiently and effectively. As a result, technologies relating to cargo handling are lagging that of the basic aircraft and is a pacing factor in the ability of the aircraft to perform its mission. The Science and Technology Objective Guide recognizes this deficiency and has assigned a high priority to the development of cargo handling capabilities that will permit external loads to be transported without restricting the aircraft envelope or operational capabilities, and that will permit hook-up and drop-off of cargo without ground crew support.

The principal performance capabilities of the aircraft, which have been achieved at very high costs, can be seriously downgraded by out-of-date cargo handling technology. For example, the ability of a cargo helicopter to fly in all weather conditions may be of little value unless it can also pick up and discharge its payload under the same conditions. With current technology, a helicopter carrying an external payload is sometimes slowed to speeds of less than 40 knots to avoid hazardous instabilities in the payload. The effectiveness of increasing aircraft cruise speed is also reduced by the long hover times sometimes required to acquire and deposit the payload. These factors, coupled with poor reliability, excessive

weight, and hazardous conditions for ground personnel, emphasize the need for a continuous systematic effort to improve cargo handling subsystem technology.

Recent advances in cargo handling R&D provide technologies that have high potential for significant improvements in combat and logistical support operations – specifically in areas of sling systems, load stabilization, and load acquisition. There remain a number of unmastered disciplines that have major impact on these functions. In addition, the advent of a high air defense threat environment introduces a new dimension to the combat support mission, with its attendant needs for new technology. The categorization in table MS–A represents the most pressing challenges to mission support roles for contemporary and future rotary-wing aircraft; these roles are discussed in appropriate subdiscipline areas of this section.

TABLE MS–A
UNMASTERED CARGO HANDLING TECHNOLOGY

• **Integral rapid load/unload/restraint for internal loads.**
• **Automated external load acquisition/discharge.**
• **External cargo handling system for terrain flying operations.**

CARGO HANDLING SYSTEMS

General. The cargo handling subdisciplines, as discussed in this section, are defined in table MS–B.

Certain of the subdiscipline areas within the overall technology of cargo handling are applicable to more than one aircraft; however, due to the rather significant differences in aircraft size and other characteristics, each area must be examined prior to initiating active work to determine whether the effort should be oriented primarily or exclusively to a particular aircraft system, or whether technology could be established or investigated that will be universal in nature.

Interfaces with other cargo handling subdisciplines and major technological disciplines must be considered throughout the program, beginning with the planning stage and continuing through test and qualification of the final hardware item. A primary example is the cargo suspension system, which includes the hoist, tension member, cargo hook, and sling. Although each of these components deals with a different technical discipline, compatibility is essential since they connect to form the total subsystem. In addition to their physical interface, their design must include allowances for flight loads, environmental effects, handling and storage, and the structural interface with the airframe. It is also likely that the cargo suspension system will contain power and signal sources for sensors and actuators that will be required for payload stabilization, payload acquisition, and precision hover subsystems. The payload stabilization system is an example of a subdiscipline that interfaces with both the cargo suspension system and the aircraft. Payload motions will be detected by sensors, from which the information will be electronically processed and fed into the aircraft flight controls or active stabilization mechanisms, or a combination of both. The interface, in this case is, therefore, very critical.

TABLE MS–B
CARGO HANDLING SUBDISCIPLINE DESCRIPTION

SUBDISCIPLINE	DESCRIPTION
VEHICLE PERFORMANCE	• **Pertains to the means by which overall aircraft systems performance can be improved in conducting tactical/logistical supply and resupply missions. These means include: coupled load analyses for improved stabilization systems; all weather day/night capability, aircraft system compatability with internal/external loads for conventional and terrain flying operations.**
PAYLOAD/ACQUISITION DELIVERY	• **Pertains to the means for improving mission effectiveness by providing payload acquisition/delivery by helicopters with minimum reliance on ground support systems.**

Figure MS–1 lists the various cargo handling subdisciplines and provides a matrix of interaction between these subdisciplines and related technologies.

SUBDISCIPLINE AREA	RELATED TECHNOLOGIES					
	AERO DYNAMICS	STRUCTURES AND MATERIALS	DYNAMICS	CONTROL	HUMAN FACTORS	R & M
CARGO SLINGS		•			•	•
CARGO HOISTS		•			•	•
TENSION MEMBERS		•				•
NONDESTRUCTIVE TEST		•				
HARD POINT CRITERIA		•				
PAYLOAD STABILIZATION	•		•	•		
PAYLOAD ACQUISITION				•	•	
CONTAINER HANDLING		•		•	•	
PALLETS AND GONDOLAS		•				
PODS	•	•			•	
CARGO HOOK		•				•
PAYLOAD READOUT	•					
INTERNAL RESTRAINT		•			•	•
CARGO COMPARTMENT CRITERIA		•			•	

Figure MS–1. Technology/subdiscipline interface.

The expected technology improvements for each mission system must interface with the IOC date of the using aircraft. The demonstration of applicable technologies for subdiscipline areas that would become part of the aircraft should, if possible, occur from 4 to 6 years prior to the IOC date. In the case of the external cargo handling system, technology that would improve the effectiveness of the mission system can be productively applied throughout the life cycle of the system; however, there are items that would normally be an integral part of the aircraft, such as payload stabilization subsystems and cargo hooks.

Performance. In the movement by helicopter of men, supplies, and equipment, effective performance of assigned missions is a function of the interacting effects of flight, payload, and operating environment. The correct assessment of generated forces and the influences on each of these elements is essential to setting operational limits, providing data for trade-off analyses, and establishing balanced design criteria for related subsystems.

Cargo Transport in Terrain Flying Environment. In operating and surviving in a high-air-defense-threat environment, Army helicopters must conduct tactical and resupply missions at altitudes below the level of enemy detection. To enable Army pilots to perform terrain flying missions, current and future helicopters must be provided with new systems, equipment, and techniques that are responsive to the special requirements of such a mission. To avoid detection and engagement by enemy air defense weapons, the pilot must fly at an altitude below 200 ft AGL, maintaining constant altitude and airspeed. If the tactical situation demands flight during instrument meteorological conditions, the helicopters will be flown at or below 200 ft AGL until arriving at the division instrumented airfield, where an instrument letdown will be performed. Upon departing the division rear, any helicopter which is higher than 50 ft AGL or cannot find a masked route is in danger from enemy air defense weapons.

Under some conditions of terrain flying, helicopter transport of supplies and equipment will be performed with payloads carried internally. Ground time for loading and unloading is a critical element of the operation, having a direct relationship to the aircraft's vulnerability, survivability, and productivity. To ensure the success of transport missions involving acquisition and disposal requires the use of internal restraint systems capable of rapid, easy installation and removal. By necessity, such restraint systems should have a low weight-to-strength ratio, yet have sufficient structural integrity to react to flight dynamic loads.

Development of effective lightweight internal cargo restraint systems requires reliable and pertinent criteria for rotary-winged aircraft. Current criteria are based upon extrapolated fixed-wing aircraft data.

A program to develop the needed internal restraint reactive load criteria and advanced conceptual restraint systems design should be formulated, based on the new criteria.

Many types of loads, by virtue of size and weight, will be carried as an externally suspended load. For this type of mission, safety and survivability require a number of essential capabilities not currently provided in Army helicopters. The limitation of the CH-47 and UTTAS in transporting such loads have been quantified (see figures MS–2 and MS–3). Candidate concepts for minimizing these limitations have

			NAP OF THE EARTH		CONTOUR		NIGHT/IMC PIO SUSCEPTABILITY
			MASKING	MANEUVERABILITY	MASKING	MANEUVERABILITY	
33000 LB GR.WT.	INTERNAL LOAD BASELINE		0%	0%	0%	0%	NONE
33000 LB GR.WT.	MIL VAN	STD SUSPENSION	102.5% (4)	41.2% (4)	94.5% (4)	16% (4)	HIGH WITH INCREASED LOAD WEIGHTS
33000 LB GR.WT.	MIL VAN	STD SUSPENSION WITH LSS	110.5% (5)	0% (1)	94.5% (4)	4.7% (3)	NEGLIGIBLE
33000 LB GR.WT.	MIL VAN	SHORT SUSPENSION	43.5% (2)	73.2% (5)	57.5% (2)	16.3% (5)	HIGH WITH INCREASED LOAD WEIGHTS
33000 LB GR.WT.	MIL VAN	SHORT SUSPENSION WITH LSS	58.5% (3)	8.3% (3)	57.5% (2)	4% (2)	NEGLIGIBLE
33000 LB GR.WT.	MIL VAN	SNUBBED LOAD	29.6% (1)	0% (1)	26.5% (1)	2.3% (1)	NONE
45000 LB GR.WT.	INTERNAL LOAD BASELINE		0%	0%	0%	0%	NONE
45000 LB GR.WT.	155MM HOWITZER	STD SUSPENSION	68.5% (4)	0% (1)	57% (3)	1% (2)	POSSIBLE
45000 LB GR.WT.	155MM HOWITZER	STD SUSPENSION WITH LSS	67% (3)	0% (1)	57% (3)	0% (1)	NEGLIGIBLE
45000 LB GR.WT.	155MM HOWITZER	SHORT SUSPENSION	28% (1)	66% (4)	31.5% (2)	7% (3)	POSSIBLE
45000 LB GR.WT.	155MM HOWITZER	SHORT SUSPENSION WITH LSS	35% (2)	0% (1)	30.5%* (1)	7% (3)	NEGLIGIBLE

*% PERFORMANCE DEGRADATION FROM INTERNAL LOADED BASELINE

Figure MS–2. CH-47 terrain flying effectiveness.

also been identified for further design analysis, breadboard fabrication, and flight test (concept evaluation). The concepts include such techniques as load snubbing, short sling suspension, multi-hook kit (UTTAS), and load stabilization (see figures MS–4 and MS–5).

External Payload Slings. Operational slings evolved from equipment and materials intended for other uses. This has resulted in a high incidence of sling failures, causing a significant dollar loss due to dropped payloads. Lack of design criteria has resulted in progressive downgrading of helicopter rated load to less than one-half of the safe working strength that would be needed to use the lift capability of the CH-47 and the CH-54. Slings are being developed that will match the capability of current and near-term cargo helicopters. Current technology does not, however, permit the degree of weight and drag reduction that will be possible with advanced materials technology. In addition, recent studies have shown no reliable method for determining the safe working strength of sling legs made of materials other than metal. Future efforts in sling technology can therefore be directed toward improvement of reliability, reduction of weight, reduction in aerodynamic drag, and development of a method of nondestructive testing.

Current sling technology for externally transported payloads does not address itself to rapid load acquisition in a high air-defense environment. A family of external cargo slings has been developed and type classified. Although these slings provide for dynamic flight payload capability from 6000 to 25,000 lb, problems in rapid load acquisition and single disposal of multidestination combined payloads have not been resolved. Also, optimum strength-to-weight ratios and maximum tension member flexibility have not been achieved.

An on-going research program is required to improve the technology for externally transported payloads in the areas of:

- Safer and reduced acquisition times.
- Individual disposal of multidestination distribution for grouped payloads.

Cargo Hoists. The CH-54 is the only current helicopter with a primary cargo hook mounted on a hoist. Smaller hoists are also used in other helicopters for personnel rescue and handling of smaller cargo

			NAP OF THE EARTH		CONTOUR		NIGHT/IMC PIO SUSCEPTABILITY
			MASKING	MANEUVERABILITY	MASKING	MANEUVERABILITY	
15080 LB GR.WT.	INTERNAL LOAD BASELINE		0%	0%	0%	0%	NONE
15080 LB GR.WT.	A22 AMMO BAG	STD SINGLE POINT SUSPENSION	67.5% (3)	44.2% (3)	43% (3)	10% (3)	HIGH WITH INCREASED LOAD WEIGHT
15080 LB GR.WT.	A22 AMMO BAG	STD SINGLE POINT SUSPENSION WITH LSS	69.5% (4)	22% (1)	43% (3)	10% (3)	NEGLIGIBLE
15080 LB GR.WT.	A22 AMMO BAG	REVISED SHORT SUSPENSION	3.5% (1)	72% (4)	14% (1)	9% (1)	HIGH WITH INCREASED LOAD WEIGHT
15080 LB GR.WT.	A22 AMMO BAG	REVISED SHORT SUSPENSION WITH LSS	9% (2)	22% (1)	14% (1)	9% (1)	NEGLIGIBLE
19500 LB GR.WT.	INTERNAL LOAD BASELINE		0%	0%	0%	0%	NONE
19500 LB GR.WT.	105MM HOWITZER + A22	STD SINGLE POINT SUSPENSION	25% (3)	29% (4)	22% (3)	5% (3)	HIGH
19500 LB GR.WT.	105MM HOWITZER + A22	STD SINGLE POINT SUSPENSION WITH LSS	25% (3)	23% (1)	22% (3)	5% (3)	NEGLIGIBLE
19500 LB GR.WT.	105MM HOWITZER + A22	REVISED SHORT SUSPENSION	17% BETTER (1)	23% (1)	1.5% (1)	1.0% (1)	HIGH
19500 LB GR.WT.	105MM HOWITZER + A22	REVISED SHORT SUSPENSION WITH LSS	17% BETTER (1)	23%* (1)	1.5% (1)	[illegible]% (1)**	NEGLIGIBLE

*% PERFORMANCE DEGRADATION FROM INTERNAL LOADED BASELINE
**NUMERICAL ORDERING

Figure MS–3. UTTAS terrain flying effectiveness.

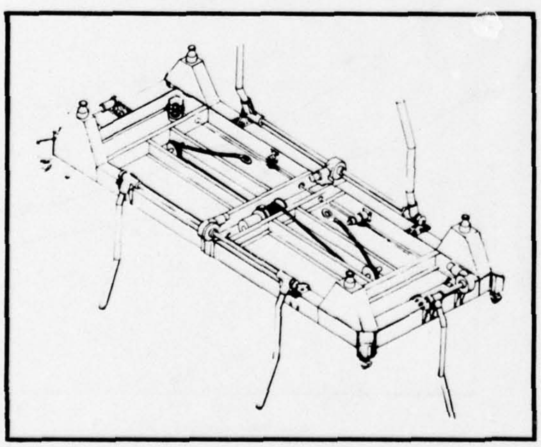


Figure MS–4. Container life adapter/load snubber.

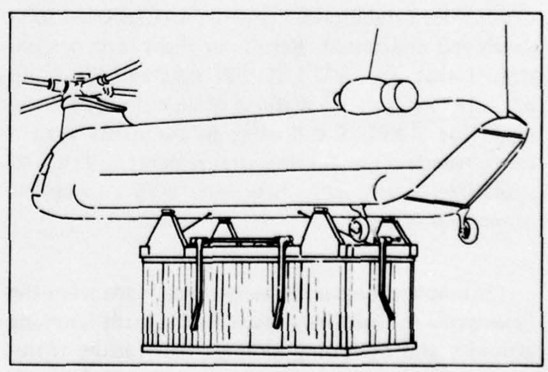


Figure MS–5. CH-47 load snubbing concept.

items. Recent investigations have shown that a pneumatic hoist drive has reliability and survivability characteristics superior to the hydraulic drives previously used. The primary deficiencies, due to the limitations of current technology, are slow cable speed and high weight. It is planned to direct future efforts toward these areas, while pointing also to improved reliability.

Tension Members. Improvement is needed in materials technology to reduce the weight of tension members. Tension members must be capable of being wound on the hoist drum, must have high strength-to-weight ratios, and must usually have provisions for transmitting power (electric, hydraulic, or pneumatic) for control and operation of the cargo hook and other devices.

Aircraft Hard-Point Criteria. A study was completed that specifies hard-point criteria for current aircraft. Because of the development of new aircraft with differing flight envelopes, a continuous updating should be accomplished to ensure applicability to the new aircraft.

External Load Stabilization. Multipoint suspension and automatic flight control systems are expected to increase allowable speeds from the current 60-80 knots to 100-120 knots by 1980. There is the possibility of a catastrophic failure if one cable breaks on a multipoint suspension system. Consequently, fail-safe and redundant design must be incorporated in a multipoint suspension system. The objective is to achieve 150 knots with the most adverse load in the 1985-95 timeframe.

Technology to support a closed loop active arm external load stabilization system (AAELSS) has been developed and tested. Results of flight tests demonstrated that the AAELSS will substantially damp pendular and yaw oscillations of an externally slung load. The AAELSS will offer an alternative system for conventional suspension arrangements and may be applicable to any cargo helicopter with a two-point suspension system.

Current techniques for suspending loads from the helicopters in flight may result in the loads assuming attitudes and exhibiting motions that can be attributed to the aerodynamic characteristics of the load. Future generations of transport helicopters will have broader performance envelopes relative to both speed and load-carrying capabilities. Investigations are under way to define the aerodynamic characteristics of typical payloads and to test experimental candidate concepts. There are, however, significant gaps with respect to the adequacy of the concepts.

Automatic Load Acquisition. The productivity of a cargo transport helicopter carrying loads externally is strongly influenced by the time required to acquire and place the load (see figure MS–6). For wholesale cargo delivery, a significant amount of the mission will be devoted to handling of containers from ships as well as from land transporters, and this handling time element will be critical. Hover time also has a major influence on the fuel consumption. Current practice for the pickup of external payloads is for a ground crewman to manually attach the cargo sling to the hook of the hovering helicopter. Since he must stand directly under the helicopter (and frequently on top of the payload), it is an extremely hazardous operation. Further, the effectiveness of higher cruise speeds can be partially negated by excessive hover times at the payload pickup and release points. Increases in both size and payload of helicopters will require larger capacity sling assemblies, the weight of which is likely to make manual hookup impossible. Technology advancement is therefore required to develop devices and procedures, for automatic hookup of external payloads, that require a minimum of prior preparation and no manual attachment.

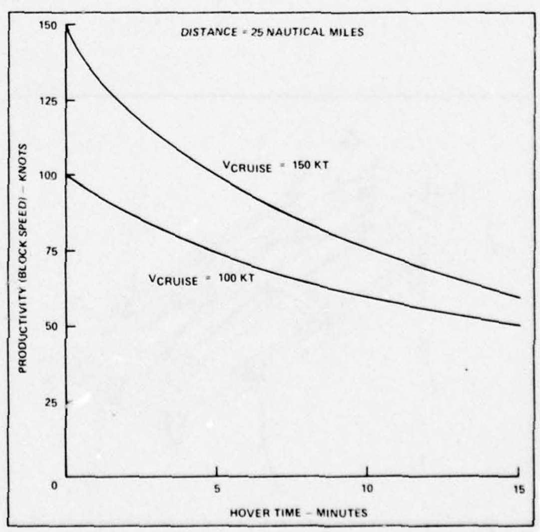


Figure MS–6. Productivity versus hover time and speed.

Container Handling Devices. A first generation helicopter container adapter for Mil-Van containers (8 by 8 by 20 ft) was fabricated and demonstrated with the CH-54 and the CH-47 helicopters. The usefulness and feasibility of this device was established. A second generation militarized version has been designed (see figure MS–7) which incorporates lighter weight structures, improved mechanization, and simpler operation. A continuing effort is being made to achieve the highest possible reliability at minimum cost. To achieve greater flexibility, consideration is being given to sizes compatible with the UTTAS for forward area rearm/refuel missions.

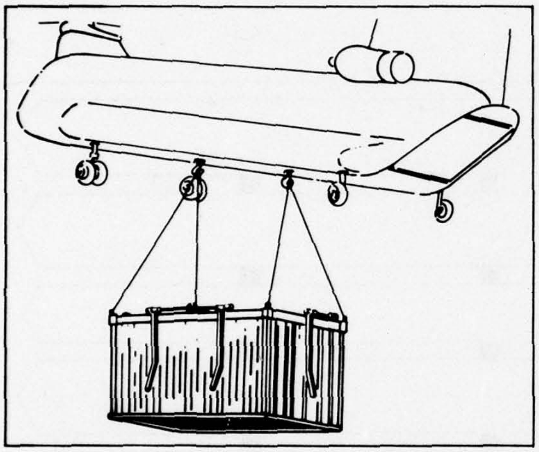


Figure MS–7. Militarized Container Lift Adapter.

Pallets and Gondolas. Pallets and gondolas will be used to carry bulk supplies and other items that do not lend themselves to transport by direct attachment of slings. Emphasis is being placed on configurations adaptable for use on various size payloads. Prototypes of externally suspended cargo gondolas have been fabricated and are being evaluated through flight demonstration test and evaluation, including flight testing on several Army cargo helicopters (see figure MS–8).

Cargo Hook Technology. Helicopter cargo hooks require technology advancement to provide acceptable reliability. Dropped payloads due to inadvertent hook release have resulted in a significant dollar loss. In addition, the poor hook reliability is a safety hazard. Work should be directed both to hook configuration and operating controls.

Inflight Payload Readout Methods. Aerodynamic loads on the payload due to downwash and maneuvers can add significantly to the actual load suspended beneath a helicopter. In addition, the actual weight of the payload is frequently unknown. The aerodynamic loading can be attenuated by modifying the distance between the helicopter and the payload. On hoist-equipped helicopters, this can easily be done in flight. The development of advanced technology flight payload readout devices will permit continuous monitoring of the payload weight. This will provide information to the pilot on which he can base appropriate corrections to the flight path or to payload suspension position for minimizing the total load carried by the helicopter.

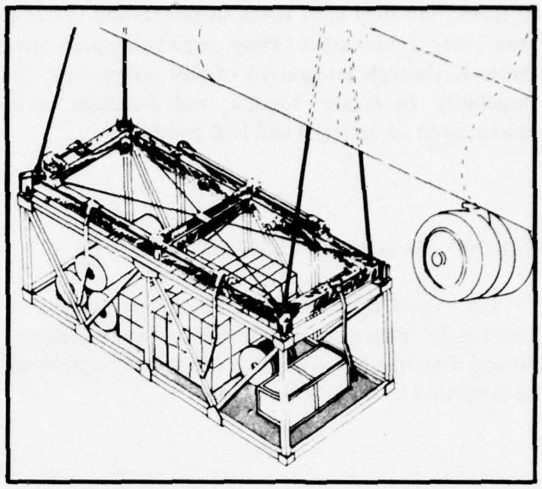


Figure MS–8. Container Lift Adapter/Mil-Van.

Internal Restraint Devices. To provide maximum safety under both flight and crash conditions, improved methods for securing internal cargo are required. Load limiting devices have been tested but have not yet been developed for Army aircraft. Improved techniques for cargo tiedown are required to ensure that advanced technology aircraft will not be handicapped by having to use outmoded cargo tiedown methods. Internal restraint devices are also discussed, from a crash safety standpoint, in the Safety and Survivability section.

Cargo Delivery Under IFR Conditions. Specialized areas of research must be integrated so that the resulting technology can be used in optimizing cargo delivery by Army cargo helicopters under IFR conditions. Research has been accomplished, to some degree, in external load stabilization, automatic external acquisitions, helicopter guidance systems, precision hover

systems, low-light-level visual augmentation systems, and other related areas. Army cargo helicopters must achieve, through integration of this technology, the capability to locate, acquire, and discharge cargo under cover of darkness and IFR conditions.

CARGO HANDLING SYSTEMS SUMMARY

The overall R&D objectives and projected achievement goals related to cargo handling systems technological development as discussed in this subsection are summarized in chart MS–I.

GROUND SUPPORT EQUIPMENT

GENERAL

Aviation Ground Support Equipment (GSE) includes a wide range of equipment required to support the operations and maintenance of Army aircraft in the field. The type of equipment varies from complex electronic test equipment to simple maintenance platforms. Consequently, this section does not address a single technology but presents plans for synthesis of numerous technology efforts, primarily by other commodity commands and laboratories, to

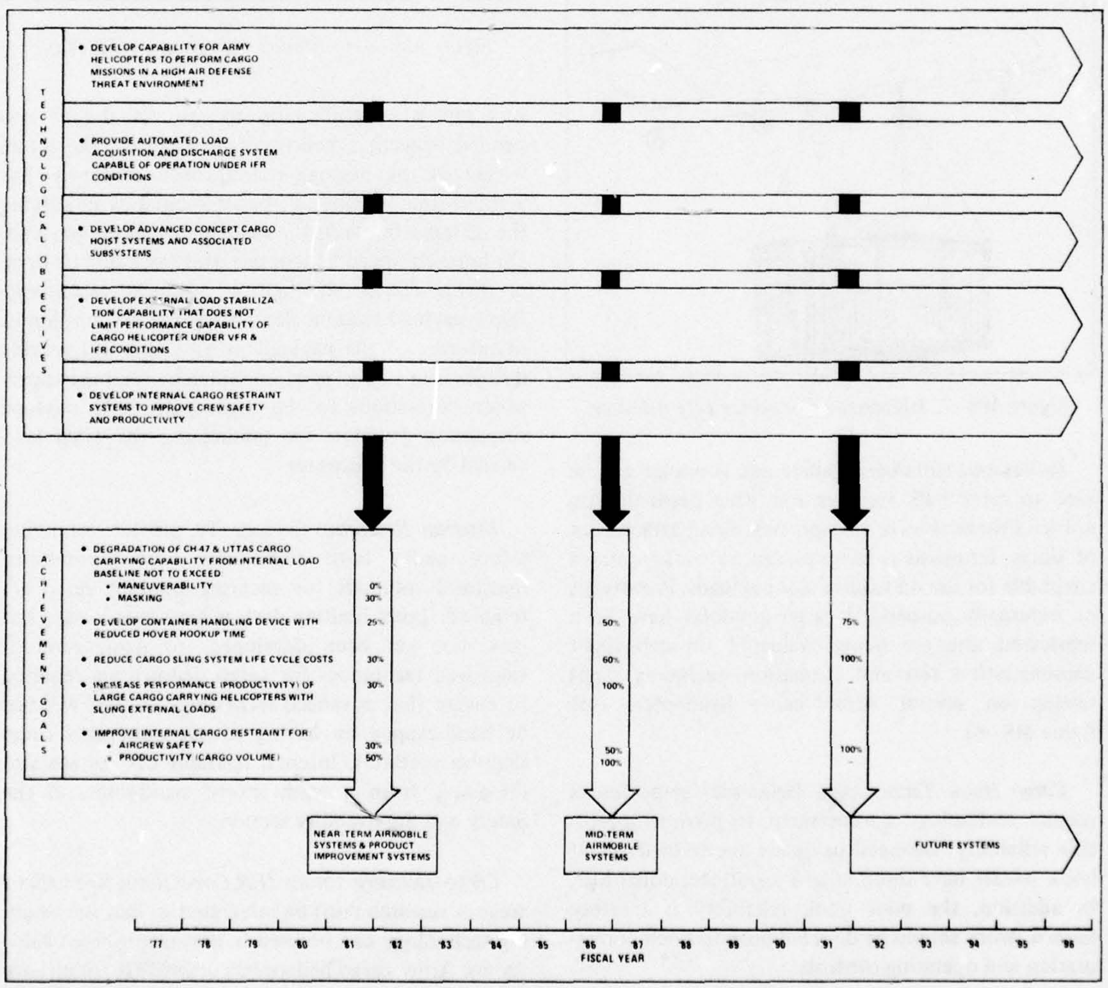


Chart MS–I. Summary of Cargo Handling Equipment Objectives and Achievement Goals.

meet the current and future GSE needs of Army aircraft. Although the basic justification for R&D in the GSE area is in support of the mission systems described in this Plan, the bulk of AVRADCOM-funded effort in this area is in response to separately approved development-requirements documents for specific end-items of GSE. Studies of the equipment needs of future aircraft or deficiencies in current equipment are the driving forces for R&D efforts.

The GSE area is divided into five functional sub-areas: ground power units, aircraft servicing equipment, test and diagnostic equipment, ground handling equipment, and maintenance facilities. Some multipurpose equipment can satisfy requirements in more than one subarea.

The near-term objectives for GSE are documented by draft and approved requirements-documents and GSE voids as related by aircraft Program Managers. Developments under these objectives are designed to support the existing fleet of Army aircraft and those currently in development, with special emphasis on the AAH and UTTAS.

Peculiar items of support equipment must be identified early in the development program so that equipment will be available to support the aircraft during its test and evaluation phase. It is probable that this new equipment will incorporate the technological advancements that are available at the time rather than requiring new technology development.

GROUND POWER UNITS

This sub-area encompasses all equipment required to supply power directly to the aircraft in support of operation (emergency ground start or checkout) or maintenance of Army aircraft in the field. Although Army aircraft have a design objective of being totally self-sufficient, and while most new aircraft do have on-board auxiliary power units, a need will remain for an emergency backup of these systems and for separate GPUs to support extended maintenance operations. Excluded from this sub-area are standard generators and compressors used to supply power to maintenance shops.

Army aircraft GPUs have not kept pace with advancing technology. As a result, they are generally excessively large, heavy, and lack adequate mobility off paved surfaces. Also, a lack of standardization has compounded already difficult logistic support problems. For example, current GPUs are powered by an array of gasoline, diesel, and turbine engines.

Figure MS–9 indicates one state-of-the-art trend in the reduction in weight of power units. While substantial weight-per-horsepower improvements are obtainable by switching to gas turbine engines, overall weight reductions are not always substantial because of the vastly increased power requirements of modern Army aircraft. Changes in the method of starting the main engine from electric to hydraulic, and then to pneumatic, have caused a wide variance of power requirement. In general the anticipated trend will be a reduction in 28-Vdc power requirements with a resultant increase in 120/208-V, 400-Hz, ac power needs. GSE producing pneumatic power is needed for AAH fire control electronics cooling during maintenance, and for emergency engine starting. Simultaneous GSE hydraulic power is needed during emergency starts and must be compatible with UTTAS and AAH hydraulic systems.

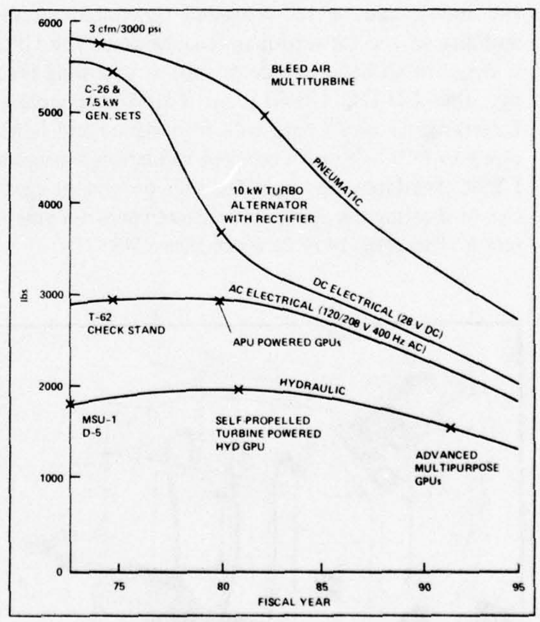


Figure MS–9. Cumulative total GPU weights.

In addition to responding to new or increased power requirements at reduced weights, R&D effort is required to significantly improve the GPU ground mobility for rough terrain operational capability, and air mobility improvements to provide rapid GPU movement to new areas by aircraft organic to the using organizations. Also, standardization on proven

military designs is required to improve the logistical support aspects of these units.

A major impediment to the achievement of the objectives in this subarea has been the lack of firm development requirements, rather than insufficient technology. Early development efforts to turbinize GSE were suspended as a result of a change in philosophy from multipurpose GPUs to lightweight, single purpose units for electric, hydraulic, and pneumatic power. Short-term improvement goals are to optimize concepts for and develop a new turbine-powered multipurpose GPU, highly mobile in rough terrain conditions, that can provide adequate electrical, pneumatic and hydraulic outputs.

An advanced ground power unit concept formulation and selection effort was completed in FY77. It defined a gas turbine powered, lightweight, multioutput unit capable of supplying all required electrical, hydraulic, and pneumatic inputs to the AAH, UTTAS, and CH-47D medium transport helicopters. The GPU will contain a 2-hr fuel supply, all cables and hoses, and be self-propelled for rough terrain mobility in the forward maintenance area. The GPU is designed to be airmobile in, and/or as a sling load by, the UH-1H, UH-60A, or CH-47 helicopters. Experimental prototypes will be designed and fabricated in FY77-78, with concept validation testing in FY79. Assistance was provided user proponent agencies in drafting the applicable requirements documentation. This concept is shown in figure MS–10.

The DOD Project Manager for Mobile Electric Power through MERADCOM has responsibility for development of the DOD Standard Family of Mobile Electric Power Generating Sources, along with the Army family of military standard engines. Currently in development at MERADCOM are turbinized 10 and 30 kW, 30/60 Hz ac versions of the 10-kW GPU to be developed and evaluated. The 10 kW, 28 Vdc GPU will be applicable to most current-fleet Army aircraft. The 50/60 Hz GPUs are designed for use as general utility power supplies. Guidelines for combat zone usage dictate development of higher degrees of GPU air and ground mobility coupled with output power characteristics compatible with the developmental aircraft subsystems. Other possible future applications are shown on figure MS–11. In general, application of standard generator sets for use as aircraft GPUs involves incorporation of chassis, integral fuel tanks, and cable storage provisions. Consideration should also be given to improving ground mobility. To achieve commonality, a multipurpose vehicle could be developed capable of powering various single or combination ground power or servicing modules.

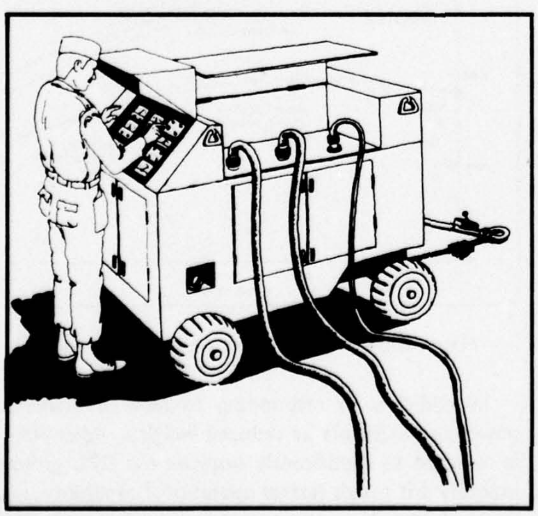


Figure MS–10. Multi-service ground power unit.

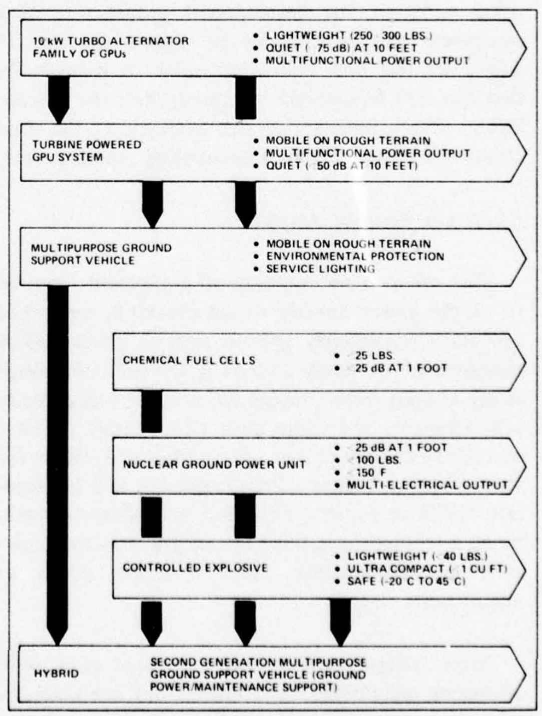


Figure MS–11. Ground power units.

AIRCRAFT SERVICING EQUIPMENT

Servicing equipment includes GSE required to replenish the aircraft with POL, ammunition, oxygen, and other consumables. The equipment needed to clean, de-ice, or preheat the aircraft at the flight line is also included. Good servicing equipment is required to allow rapid turnaround times for the aircraft. A program for establishing better aircraft servicing equipment is shown in figure MS–12.

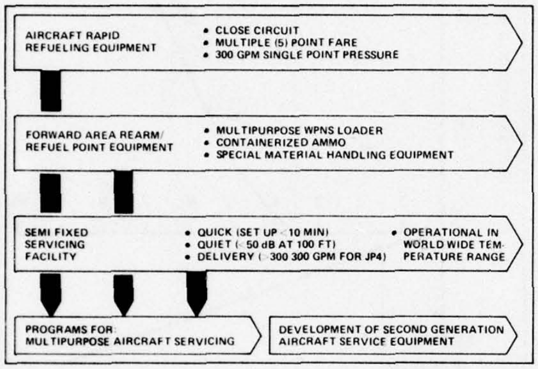


Figure MS–12. Aircraft servicing equipment.

Refueling, the most frequent servicing requirement, deserves first attention. All current Army aircraft with the exception of the OV-1 and CH-54 have only gravity refueling provisions. Closed circuit refueling provisions are being incorporated in the UH-1, AH-1, and OH-58/OH-6 helicopters to allow hot refueling, but the actual rate is still restricted by internal crossover lines or by the POL supply equipment. New development aircraft such as the UTTAS and AAH will all have provisions for single-point pressure refueling at rates up to 300 gpm. The projected payoff in reduced service time resulting from this refueling rate is shown in figure MS–13.

Rearming has to date been a manual operation, but increasing ammunition loads and a critical need to reduce rearming time has resulted in a requirement to mechanize this operation. Adequate equipment is now available for replenishment of gaseous oxygen, as used on current Army aircraft. The lack of cryogenic equipment in Army inventory has always been an overriding consideration in gaseous versus liquid oxygen trade-off studies. Field generating equipment is available, however, that can provide either liquid nitrogen or liquid oxygen to an airborne laser designator system, which has no apparent alternative to cryogenic cooling.

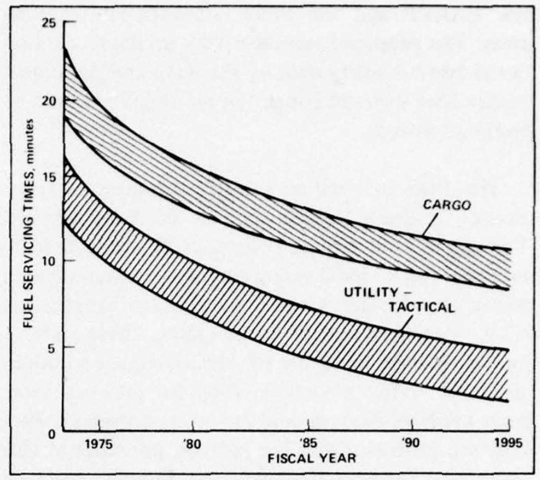


Figure MS–13. Projected aircraft servicing time (single-point refueling).

MERADCOM has development responsibility for POL-handling equipment. Current standard refueling equipment provides 50 gpm to a maximum of two points. An increased refueling capability in terms of flow rate or refueling points (or both) is required to reduce aircraft turnaround time, especially in the FARRP. With the introduction of new aircraft with larger fuel capability and higher acceptance rates, a definite need exists to exploit this capability with highly mobile pumping, filteration, container/storage equipment.

The current concept of carrying the fuel in a tanker vehicle from a tank farm to the aircraft appears to require revision. One alternative is the use of semifixed refueling points. Disadvantages of this system are the requirements for high-pressure, high-capacity pumps, and the need to layout and take up the distribution system. A second alternative is the use of pumper vehicles similar to those at large airports but capable of rough terrain operations. The vehicle needs to carry only the pump and sufficient flexible hose to connect from a central tank to the aircraft. This reduces the vehicle weight and allows greater off-ramp mobility. A third alternative is the use of encapsuled, replaceable fuel pods, which envisions replacing an empty tank (or pod) with a full tank rather than pumping fuel into the tank.

Current ongoing programs by AVRADCOM include engineering development of an Aircraft Weapons Handling Vehicle and a Cleaning and De-Icing System (CDS) for Army aircraft maintenance. The weapons-handling vehicle is intended for use in both

the FARRP and the more conventional rearming areas. The proposed vehicle is very similar to conventional bomb loaders used by the Navy and Air Force, except that soft and rough terrain mobility would be vastly improved.

The CDS is a self-contained, high-pressure spray cleaner designed to clean and de-ice Army aircraft. The unit is built around commercially available high-pressure, hot-water cleaning equipment mounted on a four-wheeled trailer with self-sufficiency features that allow operations out of austere sites. These features include storage tanks for solvent, detergent solution, and rinse water; a suction pump for drawing water from available sources; and mounting provisions for a standard generator set. The military potential of this equipment has been demonstrated through a test of a breadboard model. Additional prototypes have been procured to complete the development acceptance testing. After adoption for aviation use, plans include expanding the basis of issue for other Army applications.

TEST AND DIAGNOSTIC EQUIPMENT

This sub-area encompasses all equipment being developed for inspection, testing, and checkout of Army aircraft. To reduce the high annual maintenance costs, equipment must be developed to accurately and reliably monitor aircraft systems, and to detect and diagnose malfunctions early enough to permit timely corrections. By reducing inspection times, incorrect diagnoses, unwarranted removals, high spare parts consumption, secondary damage, and by going to on-condition component replacement, aircraft availability rates will increase and major cost savings will result. Figure MS–14 identifies anticipated cost savings for a typical aircraft currently in development.

A program on the UH-1H to collect and analyze component failure data and to design, fabricate, and test prototype Automatic Inspection Diagnostic and Prognostic Systems on the UH-1H aircraft is nearing completion. The basic objective of this effort is to test several prototype systems in an operational environment to demonstrate both system and cost effectiveness. To date, 80 percent to 100 percent detection rates were obtained on various components.

Based on a recent study, the most cost-effective approach for diagnostic equipment requires that most data be acquired, processed, and partially analyzed in flight. The complete analysis is performed with

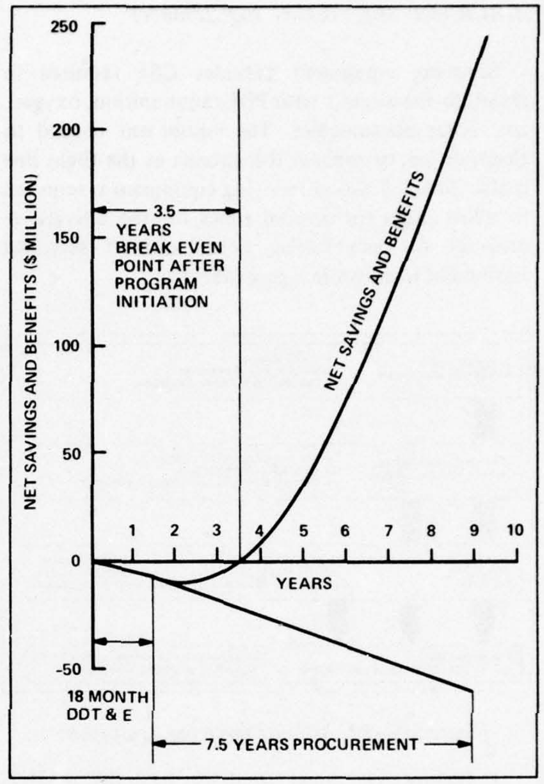


Figure MS–14. AIDAPS Hybrid I system time-phased program costs, savings and benefits.

ground equipment subsequent to aircraft landing. This approach will enable the system to display malfunctions of flight-critical components to the pilot for immediate corrective action. Such an approach requires that each aircraft be equipped with an in-flight analysis and display system. During the AIDAPS development program, this concept (plus the following two alternative approaches) will be evaluated. Alternative 1 requires that data be acquired and processed in flight but completely analyzed in a ground unit. This would enable most of the complex computer logic to be built into the ground module and shared among a number of aircraft. Alternative 2, the "maintenance ride" concept, requires that a total diagnostic system be taken for a test ride on a periodic basis or whenever a potential problem has been encountered. Except for sensors and related wiring bundles, the electronic hardware is readily removed and replaced. This approach would enable a complete system to be shared among many aircraft. These concepts will provide for a flexible program from the standpoints of economy and simplicity of aircraft equipment and operation.

Continuing efforts will be conducted in supporting technology areas to solve the deficiencies that exist in the diagnostic area. Efforts will be made to advance sensor technology so that the required rugged, accurate, reliable, and flight-compatible sensors can be provided. Correlation of sensor data with the actual condition of the component/system being monitored is required to establish needed diagnostic decision-making criteria for the establishment of parameter limits. Techniques of signal processing and data analysis will be pursued with much emphasis on vibration analysis.

The ability to forecast the remaining life of a component, once an abnormal condition is detected, will have significant implications. Present prognostic concepts center on long-term trending data and analysis taken over the full life of the component or subsystem in question. This approach requires a substantial data management effort that may not be acceptable to Army operations. Effort will be expended toward the development of prognostic techniques that do not require such a rigorous computational effort outside of the diagnostic system.

Investigations are required in the interface between a diagnostic system and such other items as engine cockpit displays. These efforts will address the areas of commonality of sensors and signal conditioning circuitry and integration of crew displays. Additional effort is required to study and develop the capability of the AIDAPS ground unit to handle automatically The Army Maintenance Management System (TAMMS) data, thereby eliminating many forms and the man-hours now required by the manual reporting done at several levels of maintenance.

GROUND HANDLING EQUIPMENT

This functional area includes all equipment required to move, jack, or secure Army aircraft on the ground. Also included are GSE items required to handle aircraft components such as hoists, slings, and transport trailers.

Current aircraft ground handling equipment is not designed to support aircraft in forward austere sites. Skid-mounted aircraft use small ground handling wheels with high ground pressure, making movement on soft or uneven terrain virtually impossible. Conventional military trucks are used to relocate aircraft because standard towing vehicles are lacking. This often results in damage to the aircraft or the vehicle. Equipment used to remove components ranges from small, fragile davit cranes to huge 5-ton wreckers. Although the M819 5-ton wrecker has vast reserve lifting and towing capacity, it is not air transportable by current Army helicopters.

Development is required in this area to provide a system, for moving the aircraft on the ground, that is capable of supporting both operations and maintenance. Much attention has been given to aircraft safety and survivability by ballistic protection, crashworthy fuel systems, and electronic warfare self-protection systems while airborne; however, very little attention has been given to the much longer periods when the aircraft is subject to enemy action while it is on the ground. By providing an adequate ground movement system capable of operating on unprepared surfaces and in rough terrain, aircraft can be moved into and under natural foliage for dispersion and concealment. If revetments are available, the helicopter can be towed in, instead of hovering. In this way the frequency of rotor strikes can be greatly reduced. Concept formulation efforts are in progress to define a system that will provide a significant increase in air and ground mobility and operation without degradation of the aircraft inherent mission reaction time.

A helicopter ground mobility system (HGMS) concept formulation and selection effort was completed under contract in FY77. The system concept defined an optimum prime mover vehicle and an increased aircraft flotation method for movement of wheeled helicopters (AAH and UTTAS) in soft, rough, unprepared terrain. Additionally, a skid-equipped, all current-fleet, helicopter HGMS adapter was defined to provide combat theater mobility for concealment and maintenance purposes. The chosen concept is lightweight, airmobile, and requires no aircraft modifications. The HGMS can also be used to load the helicopters aboard transport aircraft for inter-theater deployment. Contracted experimental prototypes will be designed and built in the FY77-78 time period. Operational verification of the concept is scheduled for FY79. Efforts have been initiated to process new requirements documentation.

Ground handling equipment used to support maintenance (including hoists, slings, and transport trailers) must be designed for efficient operation in forward areas without damaging expensive aircraft components. All equipment, especially at the lower levels of maintenance, must be airmobile and compatible with airmobile maintenance shelters. The only

approved requirements document is for an airmobile, self-propelled crane to support maintenance of all Army aircraft. The current program is for the evaluation of existng mobile hydraulic cranes. Known commercial cranes have sufficient capacity and reach to support maintenance on all Army aircraft, and they are still airmobile by CH-47 and CH-54. These cranes also have vastly improved maneuverability and visibility to enhance safe operations in a maintenance area. The crane will be complemented by the recently developed standard trailer system with appropriate adapters for handling all components.

MAINTENANCE FACILITIES

Maintenance facilities include equipment and structures normally connected with fixed airfield or maintenance shops. This sub-area, however, is restricted to deployable shelters and equipment. The current aviation maintenance shops for standard DS and GS levels are installed in semitrailer vans. While providing adequate ground mobility, these vans are excessively heavy and in general not compatible with airmobility/air transportability requirements.

Although the Army has for some time had a concept of airmobile maintenance, for all practical purposes all maintenance beyond the organizational level is still restricted to fixed-base facilities. Shelters have been developed to transport tools and shop equipment, but an adequate shop area is still lacking. Also, with the exception of an Ensure tent shelter for UH-1-sized helicopters, Army aviation does not have a portable shelter capable of housing aircraft for maintenance.

The basic objective of R&D in this area is to provide those maintenance facilities required to support a rapid movement of the maintenance base and facilitate aircraft maintenance in remote areas under all environmental conditions. Also to be considered is the problem of blackout conditions at night.

The threats of mid-intensity conflict introduce new requirements for maintenance facilities. The shelter requirements to support night maintenance on aircraft are currently under study. The programs shown in figure MS–15, supplemented by additional efforts as identified by the above study, could provide adequate maintenance facilities compatible with airmobile maintenance operations.

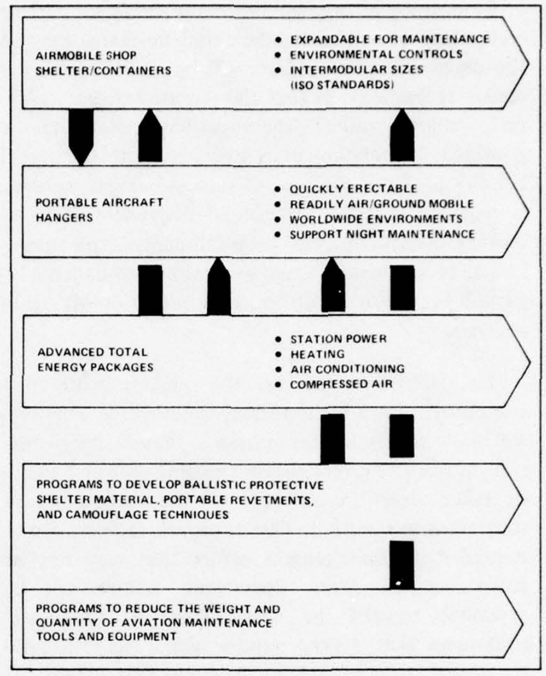


Figure MS–15. Maintenance facilities.

GROUND SUPPORT EQUIPMENT SUMMARY

The overall R&D objectives and projected achievement goals related to ground support equipment technological development as discussed in this subsection are summarized in chart MS–II.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and system elements are presented in the Technology Introduction section of the Plan. This section applies that process to the cargo handling and ground support equipment subdisciplines (for the near-term time frame) controlled by the Laboratory. The OPR is not an objective of the Plan, but is provided to show the procedure used by the Laboratory in the selection of programs within a discipline as constrained by the Army aviation R&D budget.

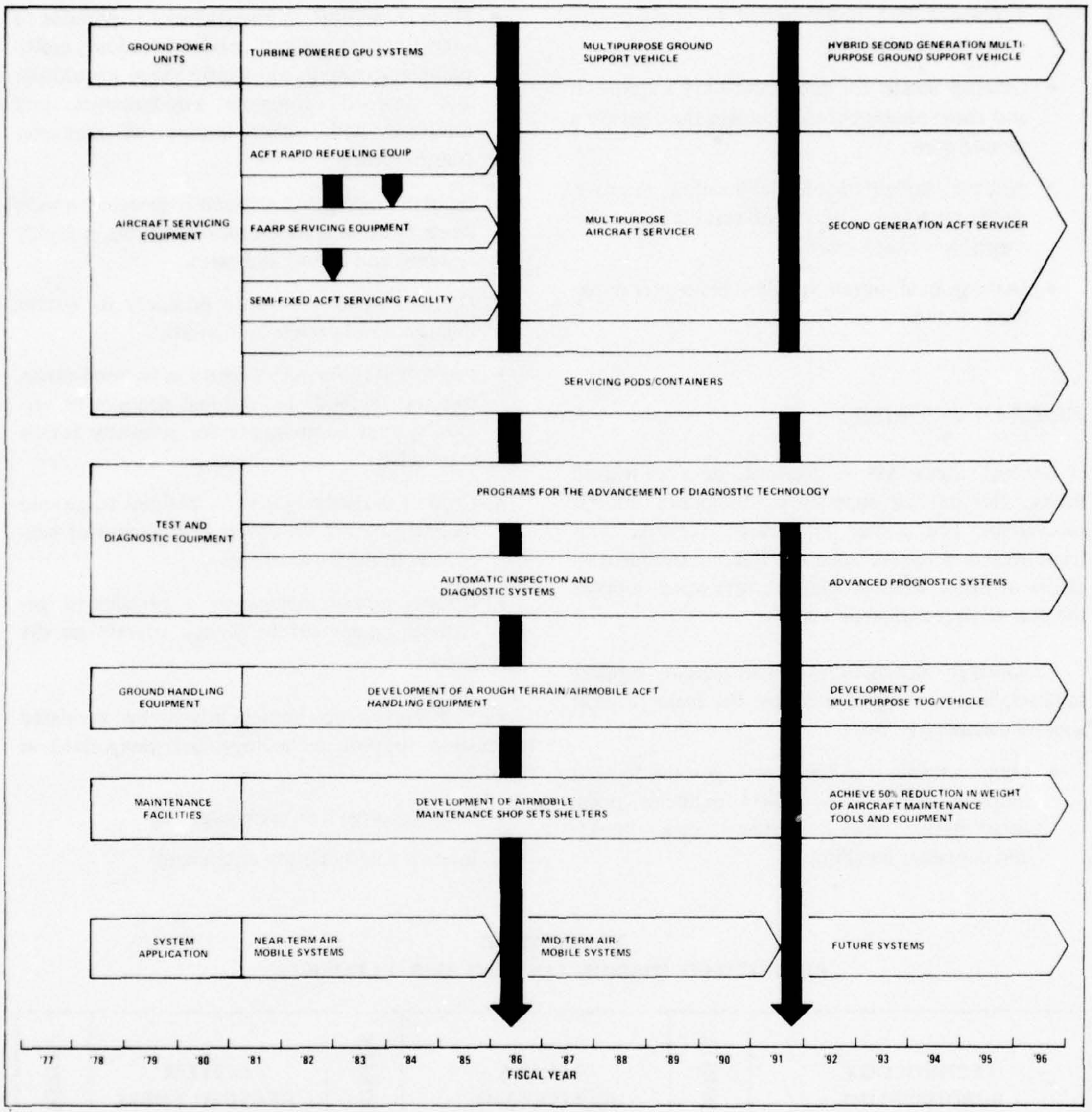


Chart MS–II. Summary of Ground Support Equipment Objectives and Achievement Goals

OBJECTIVES

The near-term program objectives for the various subdisciplines within cargo handling and ground support equipment technology can be established from the near-term quantified achievement goals listed in chart MS–I and chart MS–II.

The near-term cargo handling objectives are of two types: improvements in external load carrying devices and improvement in load acquisition and stabilization; the objective for GSE is the improvement of ground mobility for helicopters. The program objectives are:

- Achieve a 50% improvement in capabilities for cargo operation in terrain flying conditions.
- Achieve a 50% improvement in helicopter turnaround time during internal loading and unloading operations.

- Achieve a 50% improvement in cargo system component reliability.
- Develop means for automatic load acquisition and cargo placement to eliminate the need for a ground crew.
- Achieve inflight load stabilization improvements by a factor of 3, with resulting improvements in forward speed.
- Develop an all-terrain standard helicopter movement system.

PROGRAM PRIORITIES

General. Table MS–C presents, in a prioritized listing, the mission support subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The mission support subdisciplines are represented by the major topical areas as discussed below:

- *Cargo carrying and handling* – pertains to such items as cargo slings, pallets, gondolas, pods, cargo hoists, tension members, cargo hooks, and container handling.
- *Payload acquisition and restraint* – pertains to such items as penants, payload readout, multipoint suspension, automatic cargo acquisition and drop-off, container aerodynamics, and interface with other means of container transportation.
- *Internal loading and restraint* – pertains to such items as cargo/troop accommodations, restraint systems, and ingress and egress.
- *Design criteria* – pertains primarily to system dynamics and vehicle hardpoints.
- *Inspection techniques* – pertains to nondestructive test methods for residual strength of various system components but primarily textile materials.
- *Ground mobility system* – pertains to ground mobility means for covert deployment of helicopters in the forward area.
- *Ground support equipment* – pertains to specialized equipment to service aircraft on the ground.

Vehicle Subsystems. Vehicle subsystems, as related to mission support technology, are categorized as follows:

- External cargo delivery equipment
- Internal cargo delivery equipment

TABLE MS–C
PRIORITIZED MISSION SUPPORT OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Payload acquisition and restraint	I	• External cargo delivery equipment	I	• Mission performance	I
• Cargo carrying and handling	II	• Ground mobility equipment	II	• Life cycle costs	II
				• Vulnerability	III
• Ground mobility system	III	• Ground servicing equipment	III	• Safety and survivability	IV
• Ground support equipment	IV				
• Internal loading and restraint	V	• Internal cargo delivery equipment	IV	• Reliability and maintainability	V
• Design criteria	VI			• Human factors	VI
• Inspection techniques	VII				

- Ground mobility equipment
- Ground servicing equipment

System Effectiveness. In the area of system effectiveness, the primary impact of mission support is, by definition, mission performance. However, in all mission support areas, life cycle costs, vulnerability, and safety and survivability are on a nearly equal rating with performance.

Priorities. With reference to table MS–C, the mission support subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the mission support R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 mission support equipment technology development program.

The major R&D thrusts pertaining to mission support equipment technology are:

- A top priority Laboratory thrust is the development of cargo transport technology for terrain flying in adverse weather conditions; principal emphasis is on achieving reduced vulnerability, and improved safety and survivability without degradation of mission capability.
- A practical solution to the problem of helicopter movement over unimproved surfaces has not been defined. This could be a critical factor in achieving required dispersion and natural concealment in forward areas.
- Performance improvement of aircraft servicing equipment to reduce turnaround time, in particular that of the attack helicopter, is another high priority effort. Exercises conducted by TRADOC Combined Arms Test Activity (formerly MASSTER) has identified some major areas requiring excessive turnaround times. Additional effort is required to provide a satisfactory deployment of the attack helicopter.

LABORATORY PROJECTS FOR FY78 IN MISSION SUPPORT

INTRODUCTION

Mission support technological development effort is directed toward exploratory development (6.2), advanced development (6.3), and engineering development (6.4) to increase the knowledge of advanced technology concepts of mission support equipment for airmobile systems and to demonstrate those concepts.

Various commodity commands and laboratories are involved in the R&D efforts described in the technological discussion on GSE in this section. However, this program discussion deals with only the projects being performed by the Laboratory in the 6.2 and 6.3 categories.

All developmental efforts are conducted by Applied Technology Laboratory, Fort Eustis, Virginia, by either in-house efforts or by contract.

DESCRIPTION OF PROJECTS

Mission Support Technology. Project 1L262209AH76-TA VI is an exploratory development effort to develop mission support equipment that will enhance the effectiveness of military operational capabilities of Army aircraft, particularly in the forward area. Principal technology areas are cargo handling and aircraft ground support equipment. Cargo transport technology investigations have been expanded to include operation in a high defense threat environment requiring terrain flying capability. Efforts on automatic payload acquisition and stabilization systems will continue. Ground support equipment investigations will emphasize improved aircraft servicing equipment to reduce turnaround times and ground mobility to enhance covert deployment of helicopters in the forward area.

Cargo Handling Equipment. Project 1L263209DB33 is an advanced development effort to demonstrate the potential and to determine the effectiveness of new concepts and designs of cargo handling equipment. Included in this effort is the establishment of the technical feasibility and development of prerequisites necessary for the orderly transition of selected items from exploratory to engineering development. The most promising equipment,

subsystems, devices, and/or components, resulting from related exploratory development, will be fabricated for experimental and/or flight and operational testing to verify designs and validate forecasted potentials. This work will support all current and planned Army aircraft whose mission includes transporting cargo and/or personnel. The output of this program will increase aircraft safety, improve cargo handling subsystems, improve reliability, and increase overall mission effectiveness of Army aircraft.

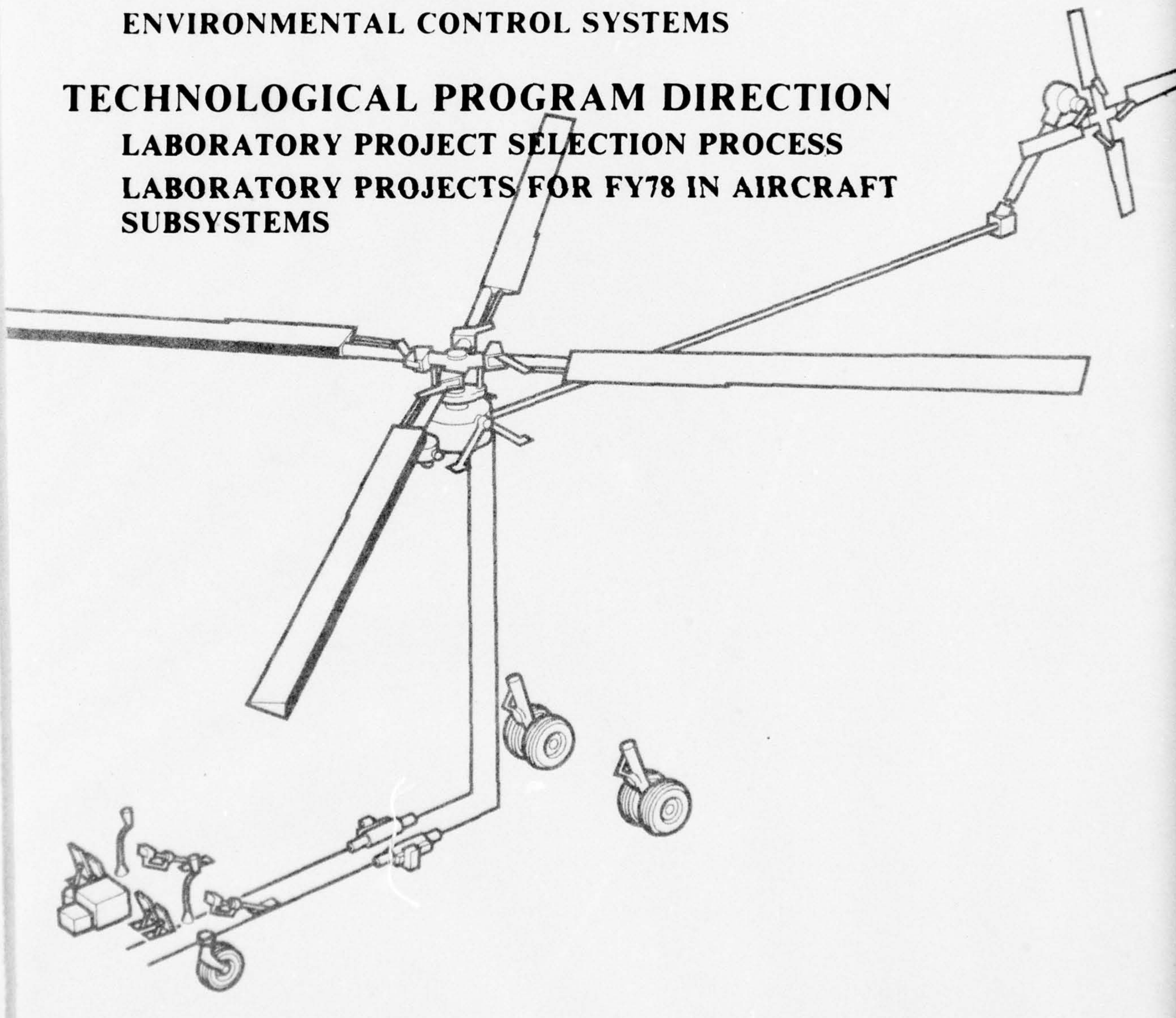
FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the mission support R&D efforts as presented in the technical discussion are shown and discussed in the Resources Required section. Those funds do not represent the current R&D program. The Command Schedule Guidance budgets for the 6.2 and 6.3 mission support R&D efforts are shown in table MS–D. Included in the table is the ratio of the mission support efforts to the total 6.2 and 6.3 Laboratory R&D efforts.

TABLE MS–D
MISSION SUPPORT TECHNOLOGY FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78	
6.2	1L262209AH76-TA VI	700	5%*
6.3	1L263209DB33	0	Less than 1%

*Does not include Project 1L262201DH96 Aircraft Weapons Technology funds.



INTRODUCTION

The term subsystems, as applied to Army aircraft and used in this section of the RDT&E Plan, applies to those subsystems of the aircraft involved with the operation and control of the aircraft with the exception of primary power, lift, mission equipment, and avionics systems.

The aircraft subsystems that have been used on helicopters in the past have, in general, been developed for fixed-wing aircraft. Little or no consideration has been given to the peculiar requirements and environmental conditions encountered by helicopters during the performance of the Army missions. This practice has resulted in low-life components, excessive maintenance, frequent mission aborts, and inability to perform needed missions.

The various mission/performance characteristics of aircraft are not ordinarily significant factors in the subsystem requirements. Thus, the results of an R&D program that has provided a technology advancement in any subsystem can be applied to all future aircraft and, in many cases, to current aircraft. On the other hand, there is little interdependence among most of the subsystems. Technological advancements in one subsystem may be accomplished, although problems remain unresolved in another.

Since a major problem in present aircraft subsystems is low reliability and maintainability, the programs conducted for improved subsystems will be closely coordinated with the reliability and maintainability R&D activities, thus making maximum use of the information obtained under that program.

The overall R&D objectives and achievement goals relating to aircraft subsystem technology development as presented in this section are shown in chart AS–I (located at the end of this section). The application of the technological improvements is keyed to near-term, mid-term, and future systems. Through PIP programs, however, any improvements could be applied to existing aircraft.

Secondary power systems, landing gear systems, flight control systems, and environmental control systems – and the specific goals and programs necessary to provide mission-oriented aircraft subsystems – are described in more detail in the following subsections.

TECHNOLOGICAL DISCUSSION

SECONDARY POWER SYSTEMS

GENERAL

Secondary power systems include electrical, hydraulic, pneumatic, and mechanical systems. All of these have one common feature: they are concerned with the conversion of energy from some type of power generation system to perform some necessary function in the operation of the aircraft system. Another common feature is that they are not greatly affected by the performance characteristics of the aircraft.

ELECTRIC POWER

Electric power requirements of Army aircraft have grown through the years, and are expected to grow further. Although the switch from direct current generators to alternating current generators has resulted in weight reductions, areas still remain where significant improvements in weight and efficiency can be realized. The weight of current alternating current generators is 1.5 to 2 lb/kVA. This should be reduced to 0.5 lb/kVA (see figure AS–1). The efficiency of the generator should be increased from the current 85 percent to 95 percent.

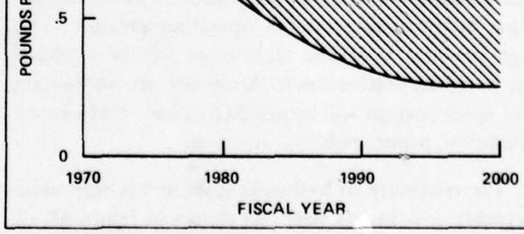


Figure AS–1. Electrical power generator weight goal.

Batteries are the most unreliable component in the electrical power system. The current MTBF for batteries – of approximately 200 hr – can be increased

if proper condition monitoring and preservation techniques are developed. The current mean time between unscheduled maintenance actions is 50 to 100 hr. Advanced technology application should increase this to more than 500 hr and also reduce the weight from 2 lb/A hr to less than 1 lb/A hr.

The electrical power distribution system has been the source of many problems centered primarily in the connectors and in control devices such as relays, switches, contactors, and circuit breakers. Power conductors are heavy and new concepts of power distribution systems should be investigated. There is a potential weight reduction of 50 percent that could result from the incorporation of advanced technology. Typical component/concepts are remote controlled circuit breakers and flat cable, flat conductor wiring, aluminum wiring and matrix interconnected wiring.

Advanced system concepts which should be examined for long-term payoffs include high voltage, direct current systems, multiplexing, and fiber optic controls.

In the long term, new sources of electricity such as fuel cells and magnetohydrodynamics (MHD) will become available. The application of these technologies to Army aricraft must be examined to determine the benefits that would be realized. Superconductors may be effectively applied in the near-term period.

HYDRAULIC SYSTEMS

Hydraulic systems are used in Army aircraft primarily to power flight controls. Some additional uses are in engine starting and cargo hoists. Current systems operate in the pressure range of 1000 to 4000 psi. Recent studies have shown that signficant weight (30 percent) and space (40 percent) savings can be achieved in fixed-wing aircraft hydraulic systems by increasing system operating pressure. This high pressure hydraulic technology will be explored for potential application to Army aircraft, and weight and space savings will be assessed as well as effects on reliability, maintainability, and cost.

The reliability of hydraulic systems has been unacceptably low in the past. As shown in figure AS–2, hydraulic system failures are a principal cause of flight aborts in Army aircraft.

Current hydraulic pumps create a pressure ripple that produces tubing wear and fatigue problems. The high vibratory environment in helicopters imposes additional stresses in the system components.

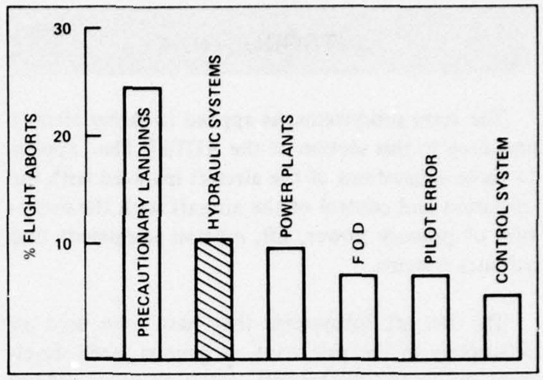


Figure AS–2. Major causes of flight aborts (noncombat).

As flight control systems become more sophisticated with the adoption of fly-by-wire concepts, the hydraulic power units must be made more reliable. Means must be provided to accomplish this without imposing unacceptable penalties in cost, complexity, and weight. *Integrated pump/actuator designs will* also be investigated.

Improved sealing techniques, increased high-temperature capability, improved system distribution methods, and improved fluids are needed to reduce power requirements and provide increased survivability and reliability of hydraulic power systems. The incorporation of fluidics in the control of hydraulic systems should be expanded.

Contamination monitoring and control must be improved to ensure increased reliability. Achievable reliability goals are shown in figure AS–3.

PNEUMATIC SYSTEMS

Although pneumatic power systems have not been employed to any extent in the past, this trend is expected to change significantly on future Army aircraft. The development of efficient air turbine motors and the exclusive use of gas turbine engines, with their available supply of pneumatic power, makes this type of power more attractive.

For aircraft utilizing advanced technology turbine engines, pressurized-air starting systems may offer significant weight and performance payoffs at costs comparable to those of electric starting systems.

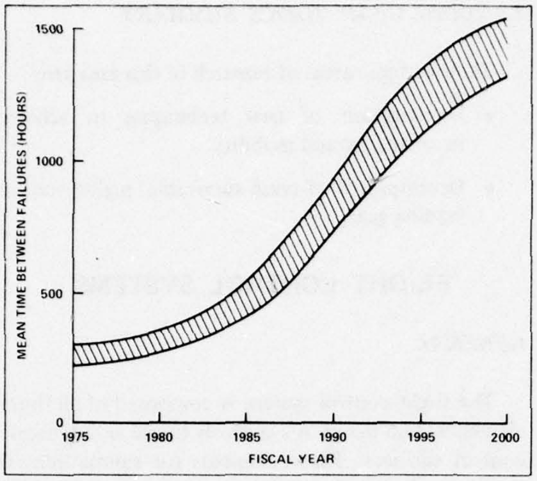


Figure AS–3. Hydraulic system reliability goal.

MECHANICAL SYSTEMS

Regardless of the type of secondary power source, the requirement to transmit, change direction, or couple the power unit to the functional unit will remain. This requirement will probably be performed by some mechanical component such as shafting, push rods, bell cranks, and rod ends. The reliability and vulnerability of these components must be improved to the extent that they will not be the weak link in the chain. The use of composite structures will contribute to the reduction in weight and increased survivability. The development of flexible joints such as elastomeric bearings to replace rod ends and bell crank pivots will significantly improve the reliability.

A relatively new concept that demonstrates considerable potential is a high-speed flywheel that can store energy for intermittent use. The use of high-strength fibers will bring this concept closer to reality. Additional work must be done to determine configurations and applications of this technology. To make this type of power device useful, advanced couplings or clutches must also be developed.

SECONDARY POWER SYSTEM TOPICS SUMMARY

The various research topics pertaining to secondary power system techology can be categorized as listed in table AS–A.

LANDING GEAR SYSTEMS

GENERAL

The ground-mobility requirements of almost all future Army aircraft include operation in the forward areas from unprepared sites. The exceptions which might not require high-flotation gear and might be expected to operate only from corps area landing fields would be some intelligence missions. Recent experience has demonstrated that operations have been restricted as a result of inadequate flotation and ground-handling capability.

Techniques must be developed to increase ground mobility without imposing unacceptable penalties in weight, speed, or handling. Advancements in this

TABLE AS–A
SECONDARY POWER SYSTEM TOPICS SUMMARY

SUBDISCIPLINE	TOPIC
ADVANCED ELECTRICAL SYSTEMS	• Improved generation and transformation devices for weight reduction, reliability and efficiency • Advanced concepts of remote and automatic control devices • Advanced battery systems for improved reliability
ADVANCED HYDRAULIC SYSTEMS	• Improved hydraulic fluids for safety and efficiency • Investigation of hydraulic system materials for improved reliability, efficiency, and weight • Investigation of hydraulic lines, connectors, and seals for improved reliability and decreased maintenance • Investigation of hydraulic system operating pressure for reduced weight and space
PNEUMATIC POWER SYSTEMS	• Investigation of pneumatic motors, ducts, and controls for decreased weight and maintenance and increased survivability

technology are particularly applicable to those aircraft that are normally moved on the ground for servicing, maintenance, or concealment, such as AAH and UTTAS.

The weight of landing gears as a percentage of gross weight would increase unacceptably if simple add-on approaches were used. The use of readily attached or detached ground support equipment can significantly widen the spectrum of approaches, such as high flotation tires or air cushion concepts to provide the necessary ground mobility far beyond that inherent in the aircraft landing gear. Skid-mounted helicopters, such as UH–1, must be provided with a means for ground movement over unprepared surfaces.

Landing gears on Army aircraft are designed to withstand sink speeds commensurate with the operational requirements of the aircraft. When subjected to crash conditions, they offer little protection to the occupants. Although criteria for crash survivable structures have been established, means for meeting these criteria have not been fully explored. This is particularly true if new concepts for meeting ground-mobility requirements are adopted.

Sought-after improvements in advanced technology landing gear that will permit aircraft to operate from any surface are shown in figure AS–4. As a reference, the figure shows also the projected weight penalty if current design practice is used to comply with the newer and more stringent performance requirements.

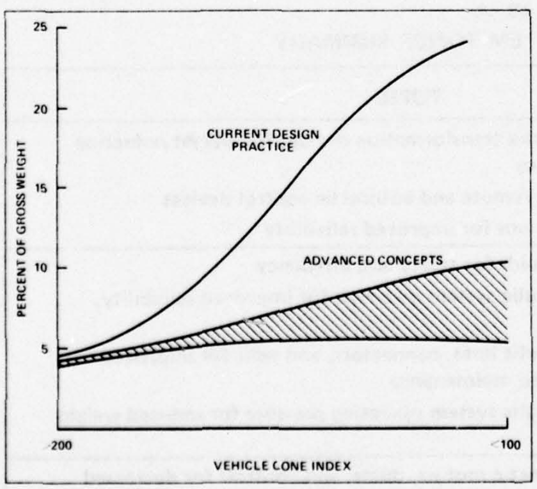


Figure AS–4. Landing gear weight improvement goals.

LANDING GEAR TOPICS SUMMARY

The two basic areas of research in this area are:

- Investigation of new techniques to achieve increased ground mobility.
- Development of crash-survivable, high-flotation landing gear.

FLIGHT CONTROL SYSTEMS

GENERAL

The flight control system is composed of all those elements from the pilot's controls to the aerodynamic control surfaces. These elements (or subdisciplines) can be electronic, fluidic, or mechanical. Also included are those elements that furnish inputs to the control system during normal flight.

The criticality of the flight control system is obvious. As aircraft grow larger and are required to perform relatively violent maneuvers, pilots are unable to provide sufficient power to control the aircraft. Thus, controls with 100 percent power boost are required. The response characteristics of the flight control system are determined by the stability, control, and handling qualities requirements of the particular aircraft system, and developments in the aircraft subsystem relate intimately to the technological advances achieved in those disciplines.

The primary problem in flight control systems has been their low reliability. The mean time between failure (MTBF) has been approximately 25 hr. With the more complex requirements on advanced aircraft systems, this figure would be expected to increase. It is anticipated that an advancement of technology and proper design for maintenance could achieve an MTBF of 400 to 500 hr, and at the same time reduce the time required to perform the maintenance. See figure AS–5 for the sought-after improvement trends over the next 20-year period.

ELECTRONIC CONTROL SYSTEM

Electronic flight control has thus far been the primary technique for implementing automatic flight control and stabilization. The technology in this area, particularly reliability, must be advanced to achieve fly-by-wire capability. A critical area in the development of reliable fly-by-wire control is proper redundancy management. Additionally, the concept of

"power-by-wire" (whereby a complete hydraulic pump, reservoir, actuator, and control package is remotely located and powered by an electrical circuit) should be considered in association with fly-by-wire systems.

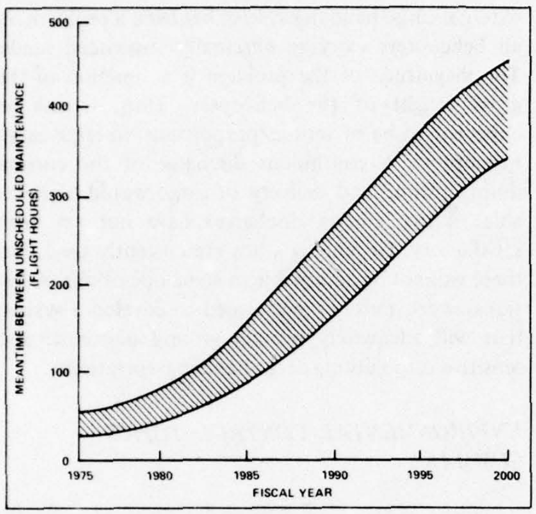


Figure AS–5. Flight control systems improvement goals.

FLUIDIC CONTROL SYSTEM

The relatively new technology of fluidics offers a potential for a more reliable, less expensive flight control system. Single- and multi-axis stabilization and auto-pilot function have been demonstrated using hydrofluidics. To develop a system that will be a backup to the electronic system, or one that will eventually be adopted as the primary system, requires that investigations be conducted to advance the technology of the sensing and transmission of signals.

The entire system should be evaluated in a dynamic simulation laboratory in which all test systems are assembled as they would be in the aircraft: hardware, wiring, hydraulics, computers, voting and switching logic, displays, controllers, and actuators. Simulated loads and airframe dynamic responses can be applied and system stability, performance, time constants, etc., can be observed and evaluated before commiting the system to flight.

FLIGHT CONTROL TOPICS SUMMARY

The research topics associated with the development of advanced systems for the three flight control system elements are shown in table AS–B. The development of the sub-element items of the mechanical system has a direct effect on the other system elements and each of the three elements has a profound effect on the development of advanced flight control system simulators.

ENVIRONMENTAL CONTROL SYSTEMS

GENERAL

Army aircraft are required to fly in all weather conditions. For rotary-wing aircraft, this requirement is now limited to operating in reduced visibility at night and in clouds. To achieve true all-weather capability, these aircraft must be operable in icing conditions, dust clouds, and in other natural and self-induced environments.

TABLE AS–B
FLIGHT CONTROL TOPICS SUMMARY

SUBDISCIPLINE	TOPIC
ELECTRONIC FLIGHT CONTROLS	• Develop stabilization systems suitable for electronic flight controls • Determine methods of load position and ground location sesning for precision hover (including effect of hoist cable dynamics) • Determine required inputs and associated sensors for stabilization system (including development of on-board computers) • Develop a fly-by-wire system
FLUIDIC FLIGHT CONTROL SYSTEM	• Determine applications for fluidic flight control systems • Develop stability augmentation systems utilizing fluidics • Develop backup flight control systems
IMPROVED MECHANICAL CONTROL SYSTEMS	• Develop improved bellcranks • Develop improved rod ends • Develop improved bearings

ICE PROTECTION SYSTEM

Ice protection systems are expected to be a requirement on virtually all future Army aircraft. Some areas, such as the windshield and engine-inlet, will require anti-icing. Other areas, such as rotor blades, can be adequately protected by a de-icing system. Ice detectors must be developed that will satisfy system requirements, and a method of describing icing conditions must be developed that is quantifiable and measurable rather than being merely descriptive, such as "moderate" or "severe." The type of ice-protection system developed for specific aircraft can be tailored to the mission requirements of the aircraft.

The most critical area at present is the rotor blade de-icing. Current technology provides the capability to de-ice the rotor blades but the weight penalty is excessive. Work must be done to exploit new rotor blade de-icing concepts that have acceptable penalties and to advance currently available concepts to eliminate the unacceptable penalties. Analytical, laboratory and flight investigations must be undertaken to thoroughly evaluate candidate concepts.

VIBRATION

The adverse vibratory environment in helicopters is a major contributor to the relatively short life of helicopter components and subsystems. The rotor-generated forces, which are carried through and at times are amplified by the structure, impose vibratory forces on the structure and anything attached to it. The use of rotor-vibration isolators offers the potential of significant reduction, particularly in the low-frequency range. In some cases, active isolators will be required and, in others, passive or self-tuning isolation will be sufficient. The mounting of subsystems and components on the structure affords another opportunity for isolation in a manner similar to that used in instrument mounts. These techniques can be applied to all future rotary wing aircraft after the technology is demonstrated. In many cases, it might be feasible to retrofit existing aircraft. Improvement in the vibratory environment imposed on aircraft subsystems depends upon advances in areas of aerodynamics and vehicle dynamics concerned with prediction, suppression, and isolation of vibrational loads.

Laboratory and flight tests of a passive vibration isolator have been accomplished with extremely good results. Vibration levels were reduced by factors of 2 to 4 with a weight penalty of approximately 2 percent of gross weight.

STATIC ELECTRICITY

The discharge of static electricity through the external cargo handling system has been a problem on all helicopters carrying externally suspended loads. The magnitude of the problem is a function of the gross weight of the helicopter. Thus, it can be expected to be of serious proportions on large cargo helicopters. A continuous discharge of the current during pickup and delivery of cargo would be desirable. Active corona discharges have not yet been satisfactory. Grounding wires are currently used, but these will not be acceptable in some operations. Additional work must be performed to develop a system that will adequately protect ground personnel and sensitive cargo during cargo handling operations.

ENVIRONMENTAL CONTROL TOPICS SUMMARY

The research topics pertaining to this subdiscipline are:

- Define and establish criteria for ice protection.
- Develop techniques for ice protection.
- Evaluate rotor vibration isolation techniques.
- Develop techniques for vibration isolation.
- Develop techniques for detection and dissipation of static electricity.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and system elements are presented in the Technology Introduction section of the Plan. This section applies that process to the aircraft subsystem discipline for the near-term time frame. The OPR is not an objective of the Plan, but is provided to show the procedure used by the Laboratory in the selection of programs within a discipline as constrained by the Army aviation R&D budget.

OBJECTIVES

The near-term subsystem objectives are primarily those that increase aircraft performance through increased efficiency and/or decreased weight or cost. Improved safety and survivability characteristics as well as reliability and maintainability are also of prime importance. The major near-term aircraft subsystem objectives are:

- Develop fly-by-wire flight control system for current and future helicopters.
- Develop ice protection system to permit operation into known icing conditions.
- Develop reliable hydraulic system components with 100 percent increase in MTBF and 30 percent weight savings.
- Develop electrical power systems with 20 percent weight reduction and increase MTBF 100 percent.

PROGRAM PRIORITIES

General. Table AS–C presents, in a prioritized listing, the aircraft subsystems subdiscipline, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. Since there is little interdependence among the various aircraft subsystems, a priority ranking is meaningless. However, for specific aircraft system mission/performance requirements, subdisciplines within a subsystem can be identified and rated. The following subdisciplines are applicable to the various aircraft subsystems and would provide a basic list for evaluation purposes:

- Performance
- Weight
- Volume

Performance can be further divided into areas such as reliability, maintainability, mission effectiveness, and vulnerability.

Vehicle Subsystems. Vehicle subsystems, as related to aircraft subsystem technology, are the systems discussed in this section of the Plan and as summarized below:

- *Secondary power system* – includes power generation system, power distribution system, and system components.
- *Landing gear system* – includes aircraft components and ground mobility systems.
- *Flight control system* – includes control input system, actuation system, and system components.
- *Environmental control system* – includes ice protection system, heating and ventilation system, air conditioning system, static electricity, and adverse environmental conditions.

System Effectiveness. In the area of system effectiveness, the primary purpose of aircraft subsystems is to increase vehicle performance. Cost, R&M, human

TABLE AS–C
PRIORITIZED AIRCRAFT SUBSYSTEMS OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Performance	I	• Environmental control system	I	• Vehicle performance	I
• Weight	II	• Flight control system	II	• Reliability	II
• Volume	III	• Secondary power system	III	• Safety and survivability	III
		• Landing gear system	IV	• Human factors	IV
				• Life cycle costs	V

factors, and safety aspects all require careful consideration.

Priorities. With reference to table AS–C, the aircraft subsystem subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the aircraft subsystem R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 aircraft subsystem technology development program.

A top priority technological thrust under the environmental control system is the development of an advanced technology aircraft ice protection system with improved vehicle performance/mission capabilities and increased vehicle safety. Operational usage and mission effectiveness of present Army inventory helicopters are severely limited during adverse weather conditions and an ice protection system has been identified as an urgent need by USAEUR. All-weather flight capability is a requirement for UTTAS and AAH.

Another high priority thrust is the development of a fly-by-wire (FBW) flight control system for Army helicopters. Past efforts have shown conclusively that FBW has significant benefits over dual mechanical controls. The development of such a system using a UTTAS prototype as test vehicle will be pursued.

A third high priority thrust is the application of advanced electrical system technology to Army aircraft. Many new concepts have been uncovered, some of which are already used in fixed-wing aircraft. These must be investigated for application to Army aircraft in the Army environment.

LABORATORY PROJECTS FOR FY78 IN AIRCRAFT SUBSYSTEMS

INTRODUCTION

Aircraft subsystem technological development effort is presently directed toward exploratory development (6.2) to increase knowledge and demonstrate advanced aircraft technology in the various subsystem disciplines. An advanced development (6.3) effort was initiated in FY77 to develop and evaluate lightweight and cost effective ice protection subsystems for application to existing and future generation Army helicopters. Funding limitations have significantly reduced R&D efforts in the 6.2 and 6.3 development categories.

All development efforts are conducted by the Applied Technology Laboratory, Fort Eustis, Virginia, either by in-house effort or by contract.

DESCRIPTION OF PROJECT

Aircraft Subsystem Technology. Project 1L262209AH76-TA VIII is an exploratory development effort to advance the state of the art for Army aircraft subsystems such that significant improvements in operational effectiveness and/or reduction in life cycle costs can be achieved. Detail investigations of ice protection, hydraulic, electrical, flight control, and other subsystems will be accomplished to define technology deficiencies and to establish means for the elimination of those deficiencies. Initial areas of work will be directed toward: reliable hydraulic systems that offer significant weight reduction potential; battery charger-analyzer-aircraft interface; advanced long-life rod end bearings for flight controls; electrical/electromechanical flight control concepts that offer greatly reduced system complexity and weight; verification of previously developed design criteria for elastromeric bearings; advanced ice protection technology; and advanced electrical systems.

Helicopter Anti-Deicing. Project 1L263209D103 is an advanced development effort to develop and evaluate helicopter ice protection systems. Work performed under Project 1L26209AH76 and 1L263209DB38 has established realistic design criteria for helicopter ice protection systems; has assessed the technology available for meeting ice protection requirements for present and future rotary wing aircraft; and identified and developed solutions for technological voids found to exist in this area. The major technology lag that was identified relates to rotor blade ice protection. Analysis of various concepts resulted in the selection of the cyclic-electrothermal rotor blade de-icing concept as being one that can effectively meet existing and future ice protection requirements. Such a rotor blade de-icing system has been proven feasible. Ice protection system penalties have been estimated for existing and

future helicopters. Penalties attendant with rotor ice protection have been determined to be excessive for application to existing small helicopters such as the OH-6, OH-58, AH-1, and UH-1. Other concepts such as ice phobic coatings, microwave, and vibratory are being investigated under Project AH76. Test evaluations of new and promising blade de-icing concepts will be initiated and include the modification of a UH-1H to incorporate the deicing concept for engineering flight test purposes. Flight test evaluations will be initiated utilizing the existing icing R&D UH-1H helicopter to evaluate icing flight characteristics of ice detectors, flight test instrumentation, armament subsystems, and lightweight advanced rotor blade de-icing systems.

Advanced Helicopter Development. Project 1L263211D157, Rotor and Control Improvement, Task 12, is an advanced effort for the development of improved flight control elements to provide improved mission capabilities, survivability, reliability, and maintainability at reduced life cycle costs. An advanced flight control program, having both long- and short-term goals, will be undertaken. The short-term effort will be the design, fabrication, and testing of a hybrid fly-by-wire (FBW) flight control system using a UTTAS prototype as the test bed. Timing of this work is intended to be such that a decision can be made relative to the inclusion of FBW in the AH-64, ASH, and possibly the UH-60. The long-range effort will encompass the development of advanced FBW concepts employing full digital computation, fiber optic signal transmission, and other 6.2 technology handoffs. The intention is to use the UTTAS FBW test bed for these developments. Flight control simulation is being conducted at the R&D Directorate's Ames Laboratory in concert with NASA.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the aircraft subsystems R&D efforts as presented in the technical discussion are shown and discussed in the Resources Required section. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 and 6.3 aircraft subsystems efforts are shown in table AS–D. Included in the table is the ratio of aircraft subsystem funds to the total 6.2 and 6.3 Laboratory R&D funds.

TABLE AS–D
AIRCRAFT SUBSYSTEMS TECHNOLOGY FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78	
6.2	1L262209AH76-TA VIII	650	4%*
6.3	1L263209D103	250	3%

*Does not include Project 1L262201DH96 Aircraft Weapons Technology funds.

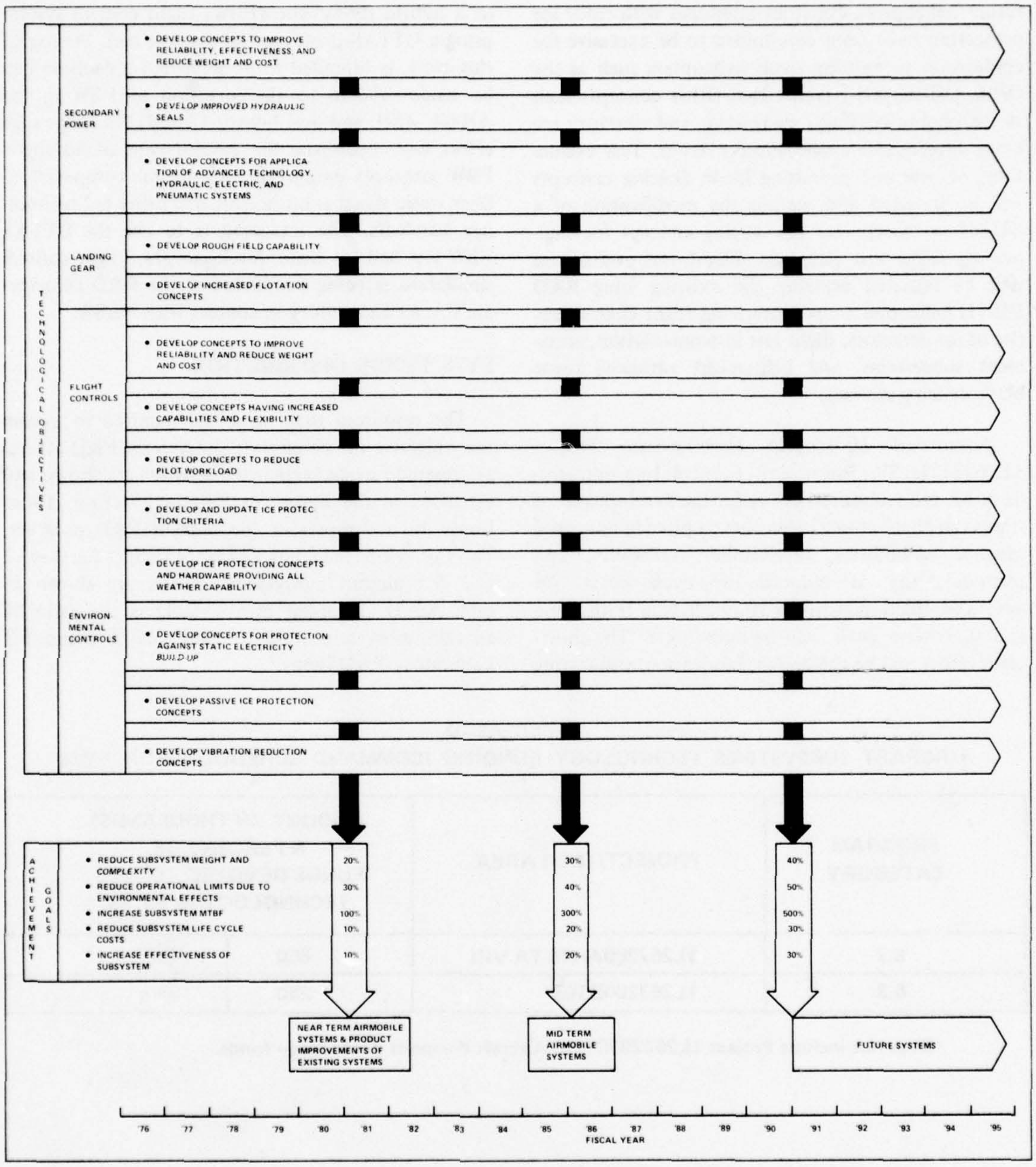


Chart AS–I. Summary of aircraft subsystems objectives and achievement goals.

INTRODUCTION

TECHNOLOGICAL DISCUSSION

GUNS

MISSILES AND ROCKETS

MUNITIONS

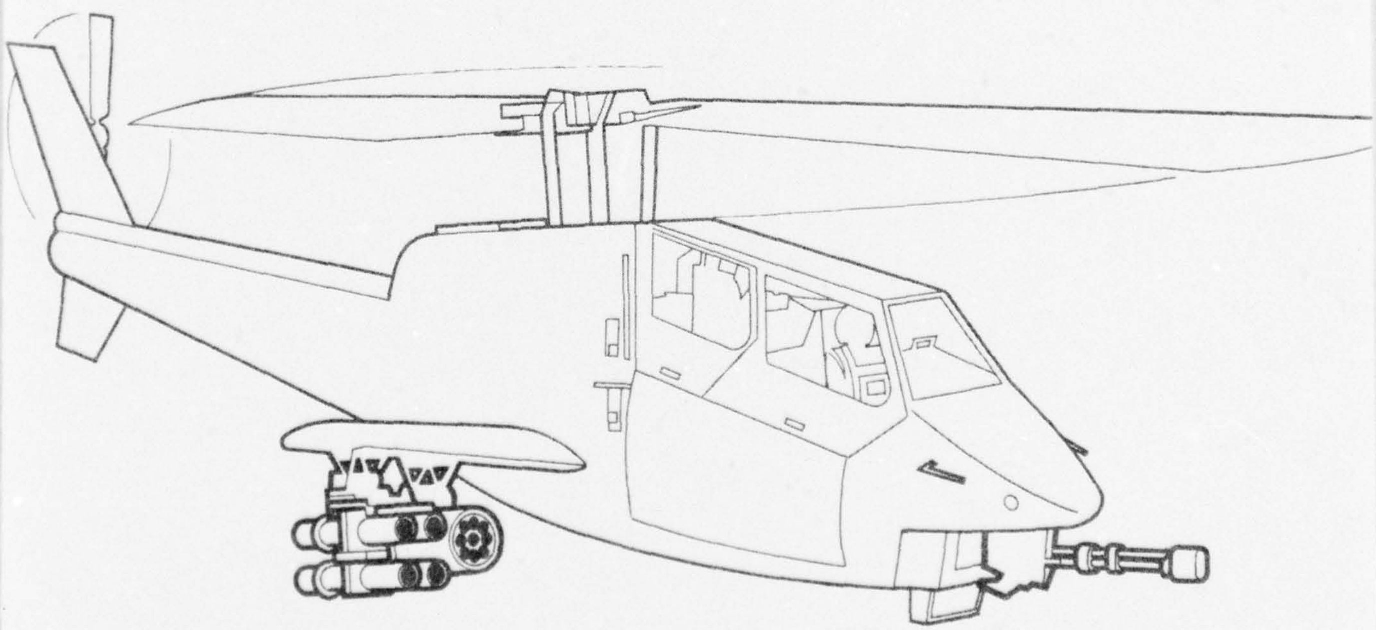
FIRE CONTROL

SYSTEM INTEGRATION

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

AVRADCOM PROJECTS FOR FY78 IN AIRCRAFT WEAPONIZATION



INTRODUCTION

The purpose of the Army aerial armament program is to provide the capability of delivering ordnance to destroy, neutralize, or suppress those targets jeopardizing ground or airborne forces in the conduct of the land combat role. For the purpose of this discussion, the aerial armament system is defined as the complete weapon system, including not only the armament subsystem and the fire-control subsystem, but also the air vehicle. Aerial armament is primarily concerned with effective ordnance delivery at a minimal cost. This capability depends on the adequacy and timeliness of the aerial armament technology base. Fundamental to the aerial armament technology are the following major areas: precision gun pointing; target detection, recognition, and tracking; warheads and terminal effects; and armament subsystem/air vehicle interface.

The U.S. Army Armament R&D Command and the U.S. Army Missile R&D Command have the responsibilities of developing weapon subsystems. More details of aircraft weaponization are found in their respective plans. The U.S. Army Aviation R&D Command becomes a participant when aircraft application is first considered, even though aircraft types are undesignated; AVRADCOM is responsible for providing the aircraft and properly integrating the weapons to ensure effective total aerial weapon systems that directly address the Army needs. Figure AW–1 depicts the subsystems directly addressing the aircraft weaponization mission.

Although the weapon subsystems cited in figure AW–1 are designed mainly for fire support type aircraft systems, such as the AH–1 Cobra series, the AAH, and the second-generation attack helicopter, some may be candidates for other emerging or future aircraft systems by providing fire support capabilities. To develop an armament subsystem compatible with the designed aircraft, it is important to recognize all of its major components. The following technological discussion highlights the five areas of weapon subsystems major research and development efforts. The last item, which is the integration of the first four, is intended to exhibit total weapon subsystem considerations.

TECHNOLOGICAL DISCUSSION

GUNS

GENERAL

For gun-type subsystems, five important measures of performance are:

- Dispersion
- Rate of fire
- Time of flight
- Range
- Mean rounds between failure

The gun effectiveness is influenced principally by:

- Angle of fall
- Dispersion
- Weapon-pointing accuracy

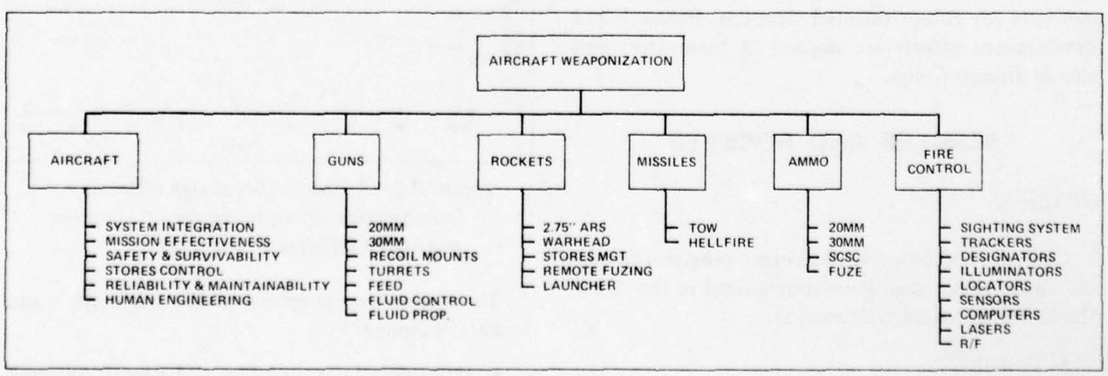


Figure AW–1. Aircraft weaponization subsystems.

AIRCRAFT WEAPONIZATION

A near-term objective is the development of the AAH armament and high impulse gun demonstration. Objectives for the 1985-1990 timeframe are depicted by the following subsystems:

- High Performance Point Fire Gun
- Advanced Automatic Cannon Development Program
- Taper Bore Gun
- Liquid Propellant Guns

ADVANCED AUTOMATIC CANNON

It is anticipated that the Advanced Automatic Cannon will have a multirole application. This project has been conceived to permit consideration of new concepts in medium caliber weapon development. Telescoped ammunition alternatives will be considered along with liquid propellant and taper bore weapons. The most promising design will be afforded the opportunity for future development

GUN/AIRCRAFT INTERACTION

Various new concepts can make guns having high impulse munitions suitable for helicopter use by means of tailoring the force-time curve. For guns, recoil attenuation offers potential for use of high impulse rounds with attenuated blast at the expense of blast overpressure against the aircraft skin. Use of recoilless guns can similarly accommodate high caliber rounds in repetitive fire, but involves problems related to breech and muzzle overpressure interacting with aircraft skin and rotor. Other adverse effects are the high temperature of the barrels and feed systems which result in high IR emission that must be reduced by cooling or shielding. Fluidic stabilization and hydraulic constant recoil mechanisms offer promising concepts for future turreted weapons. Research and development efforts are needed in these areas and also in off-axis firings.

MISSILES AND ROCKETS

GENERAL

General technology advancement programs in missile and rocket research, as summarized in the Army Missile Plan, include such areas as:

- Propulsion
- Aerodynamics
- Missile guidance
- Missile control
- Subdiscipline design

There are, however, certain areas of endeavor that may take on overriding priority characteristics in aircraft weapon applications:

- Size and weight reduction of components and subsystems.
- Vulnerability reduction of the aircraft through visible signature reduction.
- Increasing shelf life of expendables.
- Increasing operational life of reusables.
- Expanding the environmental spectrum of operability.

Space and weight, being premium items that affect both sortie firepower and endurance, enhance the value of lightweight composite structural material and electronic integration circuit efforts. Minimizing beamwidths and suppression of sidelobes of active radiators, continued test and evaluation of passive seeker and tracking techniques, and reduction of rocket motor smoke are critical to the visible signature of the attack aircraft. Effort continues to obtain the so-called "wooden round" with long shelf life and no test or minimal "go no-go" spot testing during its life span. This couples with system simplification and built-in test equipment efforts to reduce training and maintainability burdens for operational elements in the field. Technology trends in the various areas are shown in figures AW–2 and AW–3.

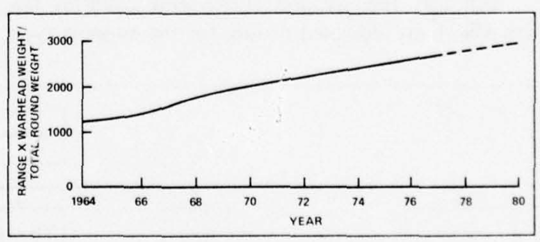


Figure AW–2. Free rocket design efficiency (combination of improved specific impulse and higher efficiency structures).

There are three programs within the missiles and rockets discipline:

- Helicopter Launched Fire and Forget Antitank Missile System (HELLFIRE)

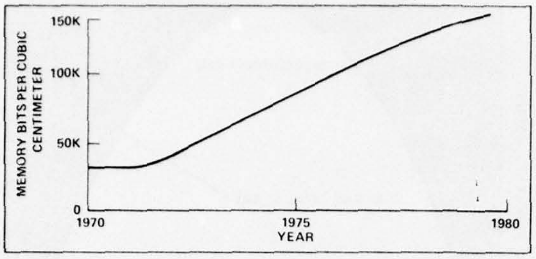


Figure AW–3. Semiconductor data handling capacity as a function of volume.

- Target Acquisition Designator System (TADS)
- Aircraft Rocket Subsystem (ARS)

The first two subsystems are operationally and functionally interrelated. While ARS has interface couplings with HELLFIRE or TOW on some aircraft, it also has some installations and many subsystem and aircraft interaction characteristics that are totally independent of HELLFIRE, TOW, or any other guided missile subsystem.

HELLFIRE

One of the major problems facing the Army today is the survivability of the attack helicopter in the postulated environment. The HELLFIRE system will greatly enhance this survivability. It is planned that the first generation of the HELLFIRE System will use laser, semiactive guidance. There are three modes of operation using laser semiactive guidance. The first is ground designation. In this mode, the ground laser designator places laser energy on the target. The reflected energy is sensed by the missile seeker. The helicopter launches the missile which homes in on the target. Current requirements are for the designators to have the capability of designating moving and stationary targets. The second mode uses designation from another helicopter, such as scout. The third mode is self-contained, that is, the attack helicopter designating for itself. The HELLFIRE Missile System can be fired in the rapid and ripple fire modes and will be capable of using modular seekers. Candidates for follow-on seekers include: IR imaging and the Air Defense Suppression Seeker. This provides the missile with a true fire-and-forget capability. The Air Defense Suppression Missile uses dual mode radar frequency/infrared (RF/IR). Designators are a vital part of the overall HELLFIRE program. The precision laser designator program involves the development of a Ground Laser Locator Designator (GLLD), and Target Acquisition Designator System (TADS) which are intended to satisfy the HELLFIRE and COPPERHEAD requirements.

AIRCRAFT ROCKET SUBSYSTEM

The thrust in rocket system improvement must be oriented toward upgrading the largely antipersonnel capability of the Vietnam era to a system that has effective application in the 1980-1990 timeframe against a broader spectrum of targets, employing low level tactics at increased standoff ranges. The objective is to achieve a reasonable and practical transition from the present performance characteristics, to a versatile aerial capability that suits the combat parameters of all levels of conflict. Current and projected system improvements are intended to upgrade effectiveness against materiel and equipment structures (including bunkered fortifications) and unarmored and lightly armored vehicles. Ancillary payloads will permit standoff target area illumination during periods of darkness, standoff day and night target marking, development of defensive radar countermeasure devices to prevent electronic detection of the aircraft, and standoff deployment of a smoke screen to prevent detection by visual means or to mask offensive tactics. System accuracy can be improved by the addition of fire control and terminal trajectory correction. Remote fuze-settings subsystem development was started under an earlier program and subsequently improved through a product improvement program. It provides a first-generation rocket fuze setting capability.

MUNITIONS

GENERAL

Aircraft weaponization requirements necessitate a variety of mechanisms capable of defeating a spectrum of targets, such as personnel, materiel, bunkers, and light and heavy armor in both the direct and indirect fire modes and a variety of countermeasure items. Related pacing technologies are germane to the nature of the proposed delivery means, whether they be gun launched, conveyed by missile or rocket, or released by dispenser. The delivery means consists of the following areas:

- Pyrotechnics
- Ammunition for aircraft weapons
- Munition handling

PYROTECHNICS

The goal of the pyrotechnics program is to provide the user an improved capability to recognize targets at night with near-daylight efficiency. Recent studies on pyrotechnic devices have shown them to be very ineffectively designed for military operations, primarily because of inadequate information on illumination requirements. It is believed that by an overall systems approach, simple state-of-the-art changes, which could be incorporated in all existing flare systems, would significantly enhance their effectiveness by as much as an order of magnitude. Design of a pyrotechnic illuminating flare system essentially consists of a compromise of the flare intensity, burning time, and parachute size. Pertinent to this compromise is definitive information on the illumination operational requirements and the effect of specific pyrotechnics parameters such as flicker, oscillation, and wind drift. In all these areas, data gaps exist. All present flare illuminating systems are designed to produce constant intensity for their total burning time (figures AW–4 and AW–5). Since all illuminating flare systems are suspended by parachute, the initial illumination on the ground is at its weakest; it gradually increases as the parachute descends. The initial illumination is inadequate, resulting in a warning to the enemy, allowing him to take cover before the illumination is adequate. These shortcomings can be eliminated by the incorporation of a varying intensity flare or increment flare.

Improved illuminating flares will enhance the night operational capability of dependent weapon systems so as to permit surveillance and effective engagement of all targets within their mission areas during hours

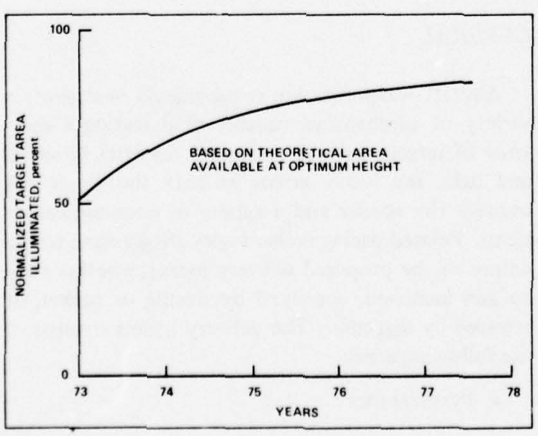


Figure AW–4. Target area illumination improvements.

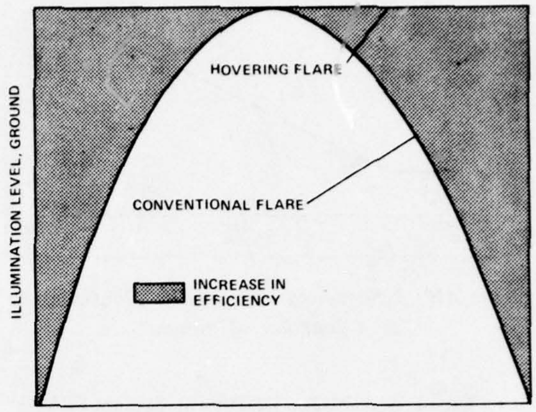


Figure AW–5. Illumination level improvements.

of darkness. The improved systems will also provide substantial reductions in logistics weight and volume, primarily because of increased effectiveness achieved by individual items through the pursuit and exploitation of opportunities and versatility offered by recent advances in pyrotechnic technology.

AMMUNITION FOR AIRCRAFT WEAPONS

General. An optimum ammunition mix study is required to permit greater effectiveness among flechette, HEDP, and WP smoke warheads against personnel and material targets. Research is needed to improve the penetration characteristics and range capabilities of single and multiple flechette-type penetrators made from steel, dense metals, or metal composites. Increased warhead volume per caliber and improved payload design would permit packaging of more efficient and effective warheads. A number of different materials and formulations will be studied for specific applications. The flexibility, adherence, flame protection, and durability of various ammunition coatings will be established. Propellant container formulations of artificial fibers combined with crystalline oxidizers will be investigated.

Shaped Charged Warheads. Shallow-cone shaped-charge warheads offer several advantages over conventionally shaped charges for defeat of light armor. Penetration is not sensitive to spin, as is a conventionally shaped charge; thus, penetration capability is constant throughout most of the trajectory. The other major advantage of this warhead is the penetration phenomenon itself. Although the hydrodynamic jet of a conventionally shaped charge creates a relatively small hole and moderate spallation behind an armor, the comparable shallow-cone shaped-charge

produces a much larger hole and considerably more spallation. Efforts are currently under way to investigate cone angle geometry, effects of spin and standoff, fuzing requirements, and characterization of the penetration phenomena.

Fuzes. Several new fuzes are being investigated in the 6.1, 6.2, 6.3, and 6.4 technical programs. These unique designs simplify and enhance the performance of the shallow cone penetration in that clutter is removed from the nose of the projectile. It is expected that the miniaturized piezo initial base detonating fuze, the TRIBO luminescent base detonating fuze, and the plastic piezo detonating fuze will emerge from the technical program. Optimization studies will be performed in the automatic cannon projectile calibers; configurations of current interest, with particular attention to fuze warhead interface problems and antiarmor and antipersonnel lethality, will be developed. Improved graze-sensitive fuzes are being developed and fuze commonality is being investigated by examining possible applications of the 25 mm XM 714 fuze to 30-mm projectiles. In addition to the above, base drag reduction devices, such as the fumer, will be developed to shorten the time of flight for air-to-ground projectiles.

Recoil Characteristics. Several concepts are currently being actively pursued to reduce peak recoil forces generated during the interior ballistic cycle; they are described in programs such as Automatic Cannon Technology (ACT). These are the compressed propellant charge concept (figure AW–6) and rocket assisted projectiles. Another concept is a modified recoilless system in which the nozzle constitutes a segment of the cartridge case. Discarding sabot projectiles are being evaluated to increase range and

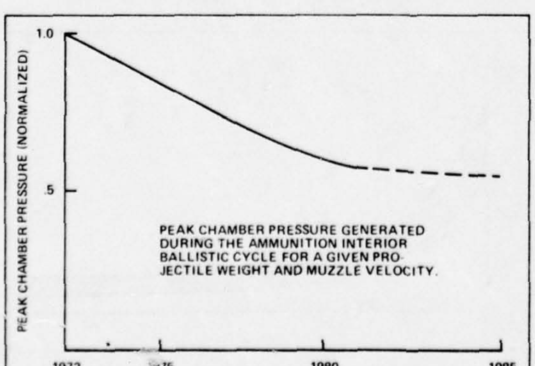


Figure AW–6. Trends in ammunition.

terminal effectiveness, and provide the aircraft with a greater standoff capability. This results in increased aircraft survivability. However, incorporation of this concept into the complete weapon subsystem package necessitates examination of aircraft damage with respect to sabot fragments. The weapon system community is continually examining fuzing concepts that permit the application of specific munitions to a wider range of application. For fuzed munition, novel fuze concepts now under consideration would allow these items to be used in various roles such as airburst or point detonating. Adoption of these concepts would, in some instances, reduce the number of munition types required to complete a specified mission.

MUNITIONS HANDLING

Munitions handling is by no means peculiar to aircraft weapons systems, and the technology will bring about improvements such as new feed techniques, in artillery, tank, and other weapons systems. Linkless, continuous, and disintegrating belts, caseless and combustible cartridge cases, and mechanisms for high-rate automatic selection and feeding must be developed for optimum compatibility with an aerial platform. The weight of the subsystems, rocket(s) launcher or munition loaded dispensers, requires ground handling equipment not now available. The details of this effort are provided in the ground support section. The subsystem designer, however, must consider ease of attachment to the aircraft, since only a limited number of weapon subsystems can be carried by the aircraft per mission. The time required for attachment and checkout of a system must be minimized to permit rapid aircraft turnaround. Munitions rearming must usually be done by hand and by one or two men while the subsystem is attached to the aircraft. Materials handling technology thus needs to be brought to bear to achieve desired improvements.

FIRE CONTROL

GENERAL

The generic area of control includes fire control, directional control and stabilization, and stores control. Fire control for aircraft weaponization is concerned with five major functions: (1) target acquisition, (2) target data evaluation, (3) preparation of the fire mission, (4) weapon aiming, and (5) projectile delivery. Directional control and stabilization involve on-board equipment designed to adjust the elevation

and traverse of weapons and maintain the aiming of the weapon to attain predetermined accuracy. Stores control consists of station, stores, and selectivity of munitions. The latter two control topics are discussed in a following subsection, System Integration.

TARGET ACQUISITION

In fire control, long range detection and acquisition of hostile forces is critical to the successful use of aircraft weaponry. At present, optical and limited night/all-weather devices are restricted to a maximum practical range of 4 km. Some limiting factors are magnification, resolution, image or sensor spatial stabilization, and environmental effects. Similarly, increased identification and recognition range capabilities are important to enhance engagement characteristics in reducing aircraft response time to a potentially hostile threat. An angular track of more accuracy can be approached with manual or full automatic techniques, provided the vibration response of the airframe is dampened by a rigid mounting structure or injected form of stabilization. Accurate range data for target tracking can similarly, although to a lesser degree, be influenced by air-frame flexure. The fire control prediction capability will have to compensate properly for aircraft flight conditions from the avionics package aspects, as well as the engagement parameters. Further, the influences of fire or launch of weapons on aircraft attitude can be provided by the fire control computer to the avionics in response to anticipatory control of the aircraft. Another interface of critical importance is that between the aircraft orientation and position relative to the target position and control of command guided munitions. Also of concern is the interface between the remote fuze setting system and the aircraft.

TARGET DATA EVALUATION

Gun errors can generally be classified as either random errors or biased errors. Although the technology in space stabilization and feedback control for missiles and space programs is well established, the application to aircraft automatic cannons has been limited to the stabilization of the gunner's sight. Closed Loop Automatic Weapon Director is an evolutionary development in fire control techniques in systems designed for attack on point targets. The closed loop system will initially be integrated into an existing turret and gun system to establish both feasibility and potential. The basic operation is to fire a burst at the target, sense the error between the target line of sight and the burst impact with respect to the target, and generate correction signals that compensate for the error. This system will correct for errors from such things as downrange cross winds that are difficult or impossible to correct by other methods. Typically, hit probabilities can improve significantly in subsequent bursts (see figure AW–7), and the technology can effect a major reduction in system error from 10-15 mils to less than 5 mils (see figure AW–8). Also important is a possibility for

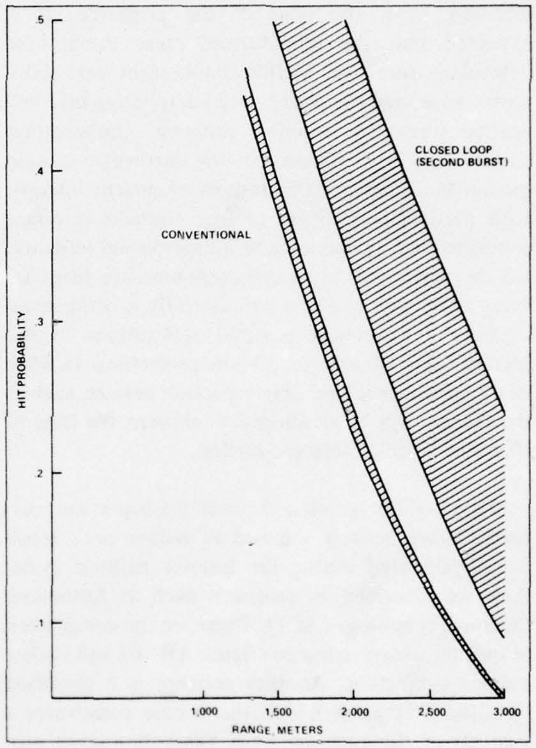


Figure AW–7. Burst hit probability: closed-loop versus conventional fire control system.

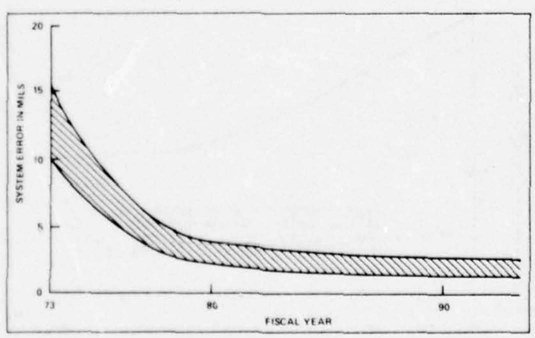


Figure AW–8. Fire control system error for automatic cannons (effects in angular milliradians, 3000 meters range).

improving system accuracy while reducing system cost. The subsystem applications include AH–1G and AAH with current and future high performance 20-mm to 30-mm guns.

TARGET DETECTION

The day/night/all-weather capability of Army helicopter weapon systems is extremely complex and cannot be discussed here in great detail. The major approaches considered here are human vision, visual optical systems, image intensifiers (I^2), infrared, and radar. The curves shown in figure AW–9 are based on experimental equipment developed in the late 1960s, and the projections are based on 1971 estimates of improvements that could be made in the near timeframe. The human eye has severely limited capabilities at night or in adverse weather. These capabilities can be extended by use of magnifying optical systems; however, the probability of detecting a target may decrease because of the limited field of view.

The IR and I^2 systems also have great potential. However, the operating environment has a major effect on the performance of both systems and the effects are not identical. For example, the I^2 devices are greatly affected by changing light levels, while the IR systems are nearly insensitive to light levels. Many other factors are also involved. Radar systems are primarily dependent on line-of-sight and the selected system parameters. Therefore, radar cannot be directly compared to any of the other systems. Because of the complexity of the technologies involved, their early stage of development, and hence their rapid growth in terms of capability and the impracticality of making direct comparisons, the curves shown in figure AW–9 should be used with extreme caution. The curves are intended to show only some of the technologies that may be applied to the day/night/all-weather operational problem. They also illustrate the fact that growth is occurring and a significant capability can be provided if required. Most likely, this would require the use of multisensors and would depend on the performance required, as well as size, weight, and cost considerations.

SYSTEM INTEGRATION

GENERAL

Weaponization of Army aircraft is known to be a problem area in which the weapon and its vehicle are highly interactive in nature. In the past, attempts at

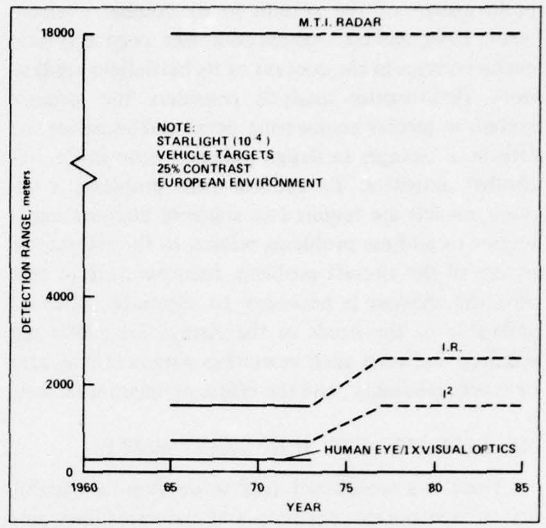


Figure AW–9. Trends in detection range.

weaponization of existing aircraft by "hanging on" a weapon have invariably produced results far short of expectations. Future developments will have to take into account the integration of the total weapon system very early in the developmental cycle. The areas in system integration include preliminary analyses, reliability, maintainability and safety considerations, aircraft structural mountings, and stores control. These areas are addressed in the following paragraphs. In addition to the basic technology impacts, there are interactions among them and with the aircraft that have considerable influence on mission effectiveness, survivability, mission endurance, and operational simplicity. Sortie effectiveness alone converts directly to reduce sortie requirements and exposure time. When improved effectiveness is coupled with the extension of standoff range, the rate of survivability improvement grows rapidly. Mission endurance is directly related to the required mission subsystems weight; therefore, integration programs should optimize endurance to achieve expected fire mission durations.

PRELIMINARY ANALYSIS

Initial system integration effort includes preliminary concepts, effectiveness, and performance analyses. Preliminary concept analysis formulates and investigates new and unique concepts that relate to problems affecting system performance. Effectiveness and performance analyses determine the effect of changes in weapon subsystem design parameters on

performance of the system in its combat environment. Effectiveness analysis addresses weapon system characteristics in the context of its battlefield application. Performance analysis considers the weapon system in greater engineering detail and addresses the effects of changes in design parameters on single unit combat activities. To address some problems, computer models are required to augment analysts' capabilities to address problems related to the interactive nature of the aircraft problem. Incorporation of cost into the analysis is necessary to approach solutions amenable to the needs of the Army. Trade-offs are required between such operating parameters as safe distance, reliability, and the effect on mission factors.

RELIABILITY AND MAINTAINABILITY

There is a recognized need to develop the capability to incorporate reliability and maintainability considerations early in the development cycle for systems and subsystems. The testing of an integrated weapon system is a critical stage in weapon subsystem development. The fabrication and test of prototypes can be used to investigate delivery error budgets, reliability factors, human factors, etc., as they relate to system performance. The improved performance of future aircraft will introduce new aerodynamic environments that affect subsystem design. The constraints to which weight, center of gravity, moments of inertia, aerodynamic drag, etc., and the tolerances to which these must be controlled will require a significant increase in the testing of a subsystem prior to its being incorporated into the complete system.

SYSTEM, SAFETY

The use of weapon subsystems on an aircraft present safety problems to both the aircraft and the weapon subsystem. The weapon subsystem must be capable of withstanding the vibration environment peculiar to helicopters. The subsystem must be capable of being safely jettisoned while loaded or unloaded. Finally, the subsystem must be unarmed until it has achieved a safe separation distance from the aircraft. Aircraft racks, pylons, and controls provide the means for releasing the stores from the aircraft. Safety interlock devices must be used in the integration of weapon subsystems to the aircraft to prevent aircraft damage and mutual interaction of munitions, particularly in proximity to the aircraft.

STRUCTURAL CONSIDERATIONS

Flexure of the aircraft structure at the location of the weapon is a problem that could seriously degrade the performance of weapon systems. Among the critical parameters are peak flexure and periodicity of structural response in relation to natural frequency of weapon structure. This area, particularly as applied to flexibly mounted weapons, has a direct effect on weapon directional control and stabilization. There also is a relationship between the airframe flexure at the location of weapon mounting and the round-to-round effects on an ordnance delivery and error budget. There is a need for improved mounting in aircraft structure and for damping of undesirable vibration-type effects. Further weapon stabilization can reduce undesirable transient disturbances to the aircraft structure resulting from launch or fire events. Moreover, performance can be enhanced by proper attention to initial design of the aircraft structure in providing improved mounting structures as well as optimal mounting locations.

STORES CONTROL

With the increasing number of possible munition subsystems that may be mounted on a given aircraft, the need for station, stores, and rate of release selectivity by the aircrew rather than by ground preflight selection, becomes increasingly more important. The major problem areas in stores control and remote fuze setting concern the attainment of controls using design and packing techniques that provide high reliability and low maintenance, yet are compatible with austere field conditions and the severe vibration environments peculiar to Army aircraft. The major interface considerations are physical location, and compatibility with aircraft power, wiring, and other airborne electronics. Fire mission aircraft, and particularly attack helicopters, are usually designed for two-man crew operation of all on-board subsystems. It naturally follows that operational simplicity of any one subsystem reduces the overall workload. It equally follows that improved maintainability and ease of mission preparation in any subsystem will be reflected in mission availability and turnaround time.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in the Technology Introduction

Section of the Plan. This section applies that process to the aircraft weaponization discipline controlled by the Army Research and Technology Laboratories. The OPR is not an objective of the Plan, but is provided to show the procedure used in the selection of programs within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines with the aircraft weaponization technology can be established from the technical discussion presented in this section. The objectives are as follows:

- Increase accuracy, range, reliability, and lethality of automatic cannons.
- Increase flexibility, range, accuracy, and provide terminal homing in missiles and rockets.
- Increase range, airburst penetration, and provide common fuzing in munitions and dispensers.
- Improve target detection, tracking, range finding, and night/all-weather capabilities in fire control.

PROGRAM PRIORITIES

General. Table AW–A presents, in a prioritized listing, the Laboratories' aircraft weaponization subdisciplines, vehicle subdisciplines, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The Laboratories' aircraft weaponization subdisciplines are represented by the major topical areas as discussed below:

- *Gun and mount* – pertains to efforts in precision gun pointing, recoil effects, and aircraft system performance to define advanced aircraft automatic cannon systems which offer capability for precision delivery of fire at long-range point and area targets.
- *Fire control* – pertains to efforts to develop the technology base and concepts for improving fire control capabilities for helicopter applications and includes improved target acquisition night/all-weather devices and automatic target detection, recognition and tracking.
- *Aerial munition* – pertains to efforts in munition drag reduction via the fumer concept, in kinetic energy penetrator, and in shallow cone shaped charge.
- *Rockets* – pertains to the "total system" approach in achieving significant gains in accuracy and lethality through efforts in fire control, launcher design, motor design, fuzing, and warheads.

Vehicle Subsystems. Vehicle subsystems, as related to aircraft weaponization technology, are categorized as follows:

- *Armament subsystems* includes automatic cannon, rockets, missiles, and munitions.
- *Fire control subsystem* – includes detection, recognition, tracking, and designators.

TABLE AW–A
PRIORITIZED AIRCRAFT WEAPONIZATION OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Gun and mount	I	• Armament subsystem	I	• Performance	I
• Fire control	II	• Fire control subsystem	II	• Life cycle costs	II
• Aerial munitions	III	• Air vehicle subsystem	III		
• Rocket accuracy	IV				

- *Air vehicle subsystem* – includes avionics, structures, stability and control, aerodynamics, and propulsion.

System Effectiveness. In the area of system effectiveness, two principal considerations are performance and life cycle costs. Performance is the effectiveness in the delivery of ordnance and can be measured as probability of kill. This term is used as a general measure, and it implies not only kill but also probability of a hit, probability of a kill given a hit, and degrees of kill, that is, incapacitation, immobility, as well as kill. Various performance capabilities are included; for example, lethality of the ordnance, ranges of armament subsystems, range of air vehicle, rate of ordnance delivery, air vehicle mobility and agility, and night/all-weather capabilities in accurate delivery.

Priorities. With reference to table AW–A, the aircraft weaponization subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUST/RATIONALE

The OPR procedure described above was used as an aid in the development of the Laboratories' FY78 program elements for the aircraft weaponization R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 aircraft weaponization program.

The major Laboratories' R&D thrusts pertaining to aircraft weaponization are:

- Develop precision gun-pointing and fire-and-forget technology for aerial armament subsystems to increase probability of kill. Current aircraft automatic cannon can operate only during the day, and under clear weather conditions. Standoff range must be increased and time to defeat the target must be decreased to improve the survivability of the attacking aircraft. Future operational requirements for aircraft automatic cannon will require greater accuracy, longer bursts, greater range, and more effective projectiles. The corresponding pacing problems involve, fire control and stabilization; higher velocities; erosion control; tubes and mechanisms suitable for much higher pressures; and more lethal projectiles (HE or KE). The priorities of essential aircraft automatic cannon technology programs undertaken by the Army are as follows: programs to increase range of tracking sensors; development of turret stabilization/recoil attenuation systems; development of automatic target detection and tracking systems, and development of saboted ammunition with extended range.

- Improve target detection, recognition, and tracking in the fire control subsystems to increase probability of kill. Current air-to-ground rocket technology is exemplified by the existing 2.75 inch Aircraft Rocket System. The major limitation is poor accuracy as a result of little or no fire control. The pacing problem is achievement of delivery accuracy in a crosswind environment, with minimum adverse launcher reactions. High priority should be placed on establishing specific programs to generate a modern technology base for rockets. There is no base specifically related to rocket systems, as such. A "total system" approach including fire control, launcher design, motor design, fuzing, and warheads, should be adopted to achieve significant accuracy and lethality gains.

- Develop warheads and terminal effects for aerial armament subsystems to increase probability of kill. Air-to-ground missile technology shows limitations in operational night and adverse weather environment with no capability to detect, track, lock-on and hit a target at night, through heavy fog, or during adverse weather. The principal problem is the achievement of night and adverse weather capabilities in guidance at an acceptable cost. High priorities have been assigned to terminal homing, guidance and control, all-weather and night operational systems development, and system modularity. A rocket-delivered illumination flare is available to support night operations.

AVRADCOM PROJECTS IN AIRCRAFT WEAPONIZATION

INTRODUCTION

Aircraft weaponization technological development efforts are directed toward research and development to strengthen the technology base of aircraft weaponry. Aircraft weaponization engineering development efforts are aimed to provide the Army inventory with advanced aircraft weapons and improved munitions. The work is conducted primarily by the U.S. Army Armament R&D Command, the U.S.

rockets. It is possible to place submunitions into a Army Missile R&D Command, the Army Ballistic Research Laboratories, the Project Manager of Aerial Rockets, and the Army Test and Evaluation Command. Additionally, aircraft-weapon subsystem interface capability and advanced development weapon system programs are conducted by the U.S. Army Aviation R&D Command through the Directorate for Development and Engineering and the U.S. Army Research and Technology Laboratories located at the Ames Research Center, Moffett Field.

DESCRIPTION OF AVRADCOM PROJECTS

Aircraft Weapons Technology (6.2). Project 1L262201DH96 is an exploratory development effort conducted by Research and Technology Laboratories to generate concepts and to develop technological advances necessary for performance, life and operation for aircraft weaponization applications. Specifically, there are four areas of research and development: gun and mount, fire control, aerial munitions, and rockets. For gun and mount, the basic methodology and critical components that are needed to improve significantly the hit probability of helicopter automatic cannon systems are developed; the relative error contributions resulting from the dynamic environment of the gun platform, and techniques to reduce the effect of environment or boresight, are determined. Efforts in this area address analytical models for improved design concepts, improved soft recoil methods, and advanced gun and ammunition technology for multiple weapon applications. For fire control, the emphasis is on analytical and simulation studies, improvement in long-range target detection/recognition capability by use of advanced sensors, image enhancement techniques, evaluation of the potential of various advanced fire-control hardware, and the generation of realistic system analysis models for improved night/all-weather fire-control systems. Efforts in this area address image stabilization concepts for multi-weapon fire control systems and application of millimeter wave radar concepts. Aerial munition work is pursued to expand the technology baseline in the air-to-ground role by the systematic investigation of the critical parameters necessary for increased system effectiveness. The technology base includes work in the following major areas: tactical projectiles, advanced gun ammunition, mass focus/fragmentation effects, and behind-armor effects. For rocket accuracy, a "total system" approach (including fire control, launcher design, motor design, fuzing, and warheads) has been adopted to generate a modern technology base to effect product-improved target area relatively independent of variations in rocket trajectory and platform stability. A high drag device is being incorporated on each submunition to terminate its trajectory and induce a near-vertical descent near the point of ejection. Other concepts are in the areas of low cost methods for inducing discrete terminal trajectory corrections, developing a target marking capability to allow integrated use of cannon and rockets on selected targets, and feasibility investigation of RPV's armed with aerial rockets for close combat.

Aircraft Gun-Type Weapons (6.3). Project 1L263206D044 is an advanced development effort conduced by AVRADCOM's Directorate for D&E to improve the capability of aircraft weapon systems employing gun-type weapons. This will be achieved by improving system accuracy, terminal effects, airframe compatibility, and overall system reliability. Specific areas of investigation will include weapon system stabilization techniques, recoil soft mounting, and improved amunition performance.

Most present aircraft turret/gun systems employ spring type recoil adapters to absorb the impact of gun recoil forces. This typically generates a high peak load at firing and a counter recoil load as the weapon comes into battery. This type of loading not only results in localized structural flexure, causing weapon inaccuracy, but also generates structural vibration throughout the aircraft that contributes to control and component reliability problems. This project provides for the advanced development of recoil control systems that average the round impulse over the entire firing cycle thus resulting in a relatively constant and lower load being imparted to the aircraft. The "active" recoil control concept was first flight-demonstrated by a prototyped mechanism installed on the lower impulse (below 40 lb-sec) 20-mm M197 weapon and XM97 turret in the AH-1G Multi Weapon Fire Control Aircraft. Knowledge gained from this effort will be used to design, fabricate, and demonstrate a similar recoil control system for medium impulse (40–80 lb-sec) 30-mm guns. The XM230 Chain Gun modified to fire XM788/789 30-mm ammunition will be used as a test vehicle. For the future, the constant soft recoil concept may be applied to higher impulse future generation gun systems, such as the experimental AMCAWS 30 (150 lb-sec). Application of the soft recoil concept, which will enable attack helicopters to reap the operational benefits of higher performance gun systems without the penalty of major airframe modification, is currently being addressed in the 6.2 program.

Another project effort based on successful 6.2 weapons research is the advanced development of the shallow cone shaped charge as the primary armor-defeat mechanism for 30-mm HEDP (high explosive dual purpose) ammunition. The performance of conventional shaped charge liners is "spin sensitive" and thus, because of spin decay over range, necessitates that penetration be optimized at a specific range. Shallow cone liners have been demonstrated to be relatively "spin insensitive"; therefore, they offer the potential capability of optimum penetration over nearly the entire engagement range. Also, ammunition equipped with shallow cones will help achieve interoperability among guns of the same caliber but with different rifling that generates differing spin rates. The test vehicle for the advanced development of the shallow cone will be the XM788/789 30-mm HEDP cartridge.

Aircraft Weapon Fire Control (6.3). Project 1L263206D043 is an advanced development effort conducted by AVRADCOM's Directorate for D&E to design, fabricate, and test advanced development hardware of fire-control devices for aircraft weaponization systems. Data derived from the development and test of this experimental hardware will contribute directly to the engineering development of operational test prototypes. Several factors make first-round hits increasingly more difficult – among them, increased aircraft performance, the availability of a wide variety of weapons (with corresponding variations in ballistics), and increased operation in adverse visibility environments (night/all-weather, vegetation/background clutter). The component and system efforts under this project provide for operation at night and in adverse weather. Types of equipment will include, but not be limited to, computers, passive automatic trackers, active ranging and tracking, night/all-weather acquisition and targeting systems, radar fire control, infrared fire control, control equipment, heads-up displays, and other sighting and viewing devices. These efforts also support the development activites for the AH-1, AAH, and ASH aircraft. There are seven tasks which are detailed below.

The objective of the automatic tracking (passive) task is the advanced development of fully automatic, highly sensitive, accurate, target tracking devices integrated into fire control sighting systems of direct view or remote view type to increase system hit probability. A technical study will be performed by a contractor on the integration of a scene-stabilizing automatic target tracker into the XM-65 TOW Cobra Sight, thereby providing more accurate TOW missile delivery through improved target tracking. The contractor will study and analyze TOW missile firing data, test reports, and films obtained during previous TOW missile system flight tests. A statement of program goals, functional specifications, potential problem areas, and a definition of test criteria for both laboratory and airborne acceptance tests will be generated. A tracker will be designed and fabricated. The tracker will be capable of being used with all sighting systems utilized on AAH, AH-1, and Scout helicopters. The device will, by virtue of radiant energy emanating from the target, remain automatically locked on the target, despite movement of the aircraft or target. Devices of this type are required so that precision tracking of targets can be accomplished without utilizing an operator whose response times are incompatible with the performance required. Application lies in determining accurate target position and velocity information for gun, rocket, missile, and free-fall weapon delivery computations, as well as in providing the means for accurately pointing targeting sensors such as laser designators, rangefinders, and missile trackers. Hardware development includes imaging and nonimaging sensors, and special-purpose signal processing electronics systems that may be interfaced with existing remote imaging sensors, such as TV and FLIR, which generate tracing error signals.

The objective of the sighting and viewing task is to provide improved sighting and viewing devices for present and future Army helicopter fire control systems. The devices generated will be used by the pilot, copilot, or both in a coordinated effort for target acquisition, tracking, and engagement. The technical data package for the lightweight helmet used with the Sperry-Univac helmet sighting system will be made available for competitive procurements. This program will be guided toward setting the 3.5-pound head leading restriction based upon empirical data, medical research, and expert opinion of eminent scientists in the field. During the development of a non-mechanical helmet sighting system, a study will be performed to address the system's boresight accuracy, retention, and essential design characteristics. The technology to be explored for the helmet sighting system will not involve the current state of the art, but will use materials and technological advancements projected for future applications.

The objective of the mast-mounted sight task is to increase Army helicopter survivability through development of airborne fire control systems to provide

reduced aircraft exposure and reaction time, and to increase accuracy. The mast-mounted sight design study will look at a stabilized sight, compatible with the OH-58 helicopter restraints, that will have the capabilities of performing the CLGP and HELLFIRE mission during day and night operations. Plans will be formulated for design studies in other types of Army helicopters. Performance specifications will be written for the mast-mounted sight in support of an RFP, and a unit procured. Detailed tests concerning performance ranges, determination of designation capability, and the effectiveness of various masking mediums will be conducted in conjunction with the user community to accurately assess the potential of mast-mounted sight.

The objective of the automatic target cueing task is to develop a fully operational automatic target cueing system which can be used in conjunction with electro-optical remote view systems to increase target acquisition performance of airborne observers and at the same time decrease helicopter exposure times. This task will include the initiation of the design of a real-time processor which will process remote sensor output signals over the entire field of view. The system will be designed for pod mounting to accommodate testing on the current attack, advanced attack, and advance scout helicopters. The engineering design effort will provide for maximum miniaturization of all electronic components to assure minimum system size and weight. Decision algorithms will be implemented in the current laboratory breadboard system and optimized in accordance with the testing of the hardware. A prototype automatic target cueing will be fabricated and flight tested to determine its operational effectiveness to provide an automatic target detection capability for use with remote view imaging sensors.

The objective of the air to air targeting task will be to develop a fire control system capable of providing the attack helicopter with the air to air defensive capability required to successfully engage an enemy airborne threat. Flight testing will be conducted to determine the suitability of existing helicopter sighting stations for use in effectively engaging moving targets. Of particular interest is the ability of the gunner to effectively track airborne targets capable of maneuvering at a significant rate of speed. The tests will be conducted utilizing the multi-weapon fire control aircraft as the test vehicle: it is representative of advanced, state-of-the-art fire control/sighting capability. Concurrent with the flight test, an in-depth analysis of air-to-air fire control requirements will be conducted. This investigation will include a determination of component and software requirements. Included in this evaluation will be an initial analysis to compare existing millimeter wave radar systems. In the event that these efforts indicate that an effective air-to-air capability is feasible, development of such a system will be initiated.

The objective of the closed loop fire control task is to increase the overall effectiveness and survivability of attack helicopters through the significant increase in weapon delivery accuracy. Efforts in this task will accomplish this through maximum use of on-board sensors and/or modification of existing hardware. The existing XM-127 Multiweapon Fire Control System is an example of a full-solution fire control system comparable to that which will be available on the advanced attack helicopter or the AH-1S Cobra helicopter. This system will be modified to provide an even greater precision weapons delivery capability through the implementation of a closed loop fire control system technique, an on-board trajectory solution technique, and/or modification of existing sensors to provide reduced computational errors in the fire control computer. The first of these to be implemented and demonstrated will be a closed loop fire control system technique.

The objective of the internal bearing stabilized sighting unit task is to demonstrate the feasibility of stabilizing high acuity visionics payloads via an internal bearing gimbal concept coupled with a passive three-axis isolator system. The internal bearing stabilized sighting unit is a novel approach to attain necessary stabilization capability for helicopter visionic and fire control systems of the future. It appears to have superior performance potential because of wide-band vibration isolation from the airframe while maintaining the capability for precision measurement of the angular orientation of the line of sight relative to the airframe, low conversion of vehicle linear and angular accelerations into payload angular accelerations, usually low stabilization system weight, payload weight ratio, and improved payload reliability due to the more favorable environment. The achievement of a practical system depends upon careful detailed design involving unusual axis configuration and novel components, including a concentric three-dimensional wide-band vibration isolater, a wide-gap torquer employing $SmCo_5$ magnetic materials, two short-stroke actuators, and a two-axis auto-collimator angular pickoff. It will also be

necessary to develop the angular conversion program, based on the critical components have been breadboarded in accordance with careful design considerations.

Aircraft Gun-Type Weapons (6.4). Project 1H264202D133 is an engineering development effort conducted to provide the Army inventory with advanced automatic gun and ammunition systems. Primary applications for these efforts are attack helicopters, the AAH and AH1-S.

The current task (managed by AAH PMO) consists of the development and qualification of 30-mm ammunition, XM788 target practice (TP) and XM789 high explosive dual purpose (HEDP) and XM799 high explosion incendiary (HEI) (qualified for Navy use only). The goal is to satisfy the ammunition requirements of the Army's AAH and the Marine Corps' AV-8A Harrier aircraft. In an attempt to achieve ammunition inter-operability among the NATO countries, the AAH weapon chamber will be designed in accordance with the existing NATO Standardization Agreement thereby requiring only one configuration of 30-mm ammunition. Inter-operability tests with the American 30-mm XM230 Chain Gun, the British 30-mm ADEN, and the French 30-mm DEFA weapons and ammunition will be conducted. Significant technical improvements of the XM788/789 ammunition over the existing European rounds will be aluminum case for lighter weight, graze-sensitive fuze for low angle impact, and high explosive dual-purpose warhead for combined armor penetration and fragmentation effects.

Other planned tasks (managed by AVRADCOM's Directorate for D&E) for this project include the transition of weapons programs for advanced development (see 6.3 Project 1L263206D044) to engineering development. These efforts will include the completion of the development of the medium impulse, constant, soft recoil control system for turret mounted 30-mm guns. The objective is reduction of high impulse forces that can damage the aircraft structure and shorten component life, cause helicopter control instability, make it difficult to control weapon pointing, and make it difficult to sight and track targets.

Another planned task is the completion of the development of Shallow Cone Shaped Charge (SCSC) liner as the primary armor defeat mechanism for 30-mm HEDP. Integration of the new "spin insensitive" liner will provide the capability of optimum penetration over the entire engagement range. In addition, SCSC will help achieve 30-mm ammunition inter-operability in guns of the same caliber but different rifling that impart a variety of spin rates.

Aircraft Rocket System (6.4). Project 1H264202DL62 is an engineering development effort conducted by AVRADCOM RD&E to reduce the vulnerability of Army helicopters by providing a significant increase in standoff capability with no follow-in to target commitment, accuracy, and effectiveness against a complex target array. This effort includes the development of a multipurpose submunition warhead, smoke screen warhead, improved illumination warhead, lightweight launcher, boresight retention and rapid rearm rack, and rocket motor improvements.

The Multipurpose Submunition Warhead will provide the capability to deliver ordnance with multi-effects from aerial rockets. The approach will be to continue development of the warhead as a submunitioned canister configuration which provides a high volume of fire power per unit. The submunition provides multipurpose lethality against personnel, materiel, and armored targets. Parametric studies supported to engineering tests project a significant increase in anti-personnel effectiveness using rockets against area targets and likewise an increase in hit probability against individual elements of an array. Static and dynamic firings using a full caliber submunition demonstrated the ability to defeat personnel, materiel, and the top surface of armor vehicles. The warhead configuration will incorporate remote setting fuzing.

The Smoke Screen Warhead will provide the user with a capability to deliver tactical smoke screens from attack helicopters, without over-flying the target area. The approach is to utilize the white-phosphorus (WP) wick concept emanating from the advancement development phase, packed in clusters in a canister, to form a pattern of smoke generators among the target array. The resultant persistent cloud serves to obscure the enemy's vision, disrupt his own movement, and prevent his sighting of friendly targets or activities. The canister will be packaged in the 2.75-inch cargo warhead. The WP/wick approach was selected over alternatives of WP containing a plasticizer, vulcanizing agents, and epoxy resin, as well as attempting to convert the WP to red phosphorus after filling. All of these have proven to be unsatisfactory as munition fills. WP was selected as the smoke agent over other agents because it produces the best smoke cloud; it has an auto-ignition capability, and there is a

broad technology base for manufacturing WP munitions.

An improved illumination warhead will be developed to replace the standard M257 illumination warhead. This warhead will have the capability to utilize a remote-settable fuze with variable range. The approach is to design the warheads to the same outline dimension as other new 2.75-inch warheads. The major design problems are drogue parachutes and main parachutes that will withstand the opening and deceleration forces encountered at minimum range.

A Lightweight Launcher (LWL) is being developed to reduce the weight of the Aircraft Rocket Subsystem. In addition to weighing less than the current 2.75-inch rocket launcher the LWL will be suitable for use as a rocket shipping container, capable of operating under moderate icing conditions, and compatible with the self-loading/boresighting equipment being developed. The LWL will also be capable of firing remote settable fuzes. Weight will be reduced by using plastic foam injected in the interstices between the paper tube cluster and skin. The rocket detent, electrical contact, and wiring harness will be modified to accommodate foam and to reduce cost and weight. The strong-back/suspension lug of the LWL will provide a self-loading and auto-boresighting capability.

The current lug/rack interface will not allow for required boresight retention and rapid rearming. A task has been initiated to provide an external stores rack that will eliminate the need for reboresighting every time a store is placed on a helicopter. The approach is to test an alternative lug and interface method. The test results will be reviewed and an optimized design formulated. Prototype store racks will be purchased and laboratory tested prior to joint DT II/OT II/OT II with the LWL. The rack will be designed to fit the AAH pylon without modification, and the AH-1 pylon will be redesigned to accept the new rack.

A Rocket Motor Improvement program has been initiated to make the Navy-designed and standardized MK66 2.75-inch rocket motor compatible with standard 2.75-inch rocket launchers, and to improve the hover fire accuracy. These objectives can be obtained by modifying the fin and nozzle assembly of the MK66 motor to make them compatible with the LWL. The MK66 detenting groove with electrical contact in the bottom is located at the aft end of the fin and nozzle assembly. The standard launcher and the LWL are designed for the MK4/MK40 motors. These motors have the detenting device located approximately 7 inches forward in the tube and the electrical contact centered at the aft end of the tube.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objectives of the aircraft weaponization R&D efforts as presented in the technical discussion are shown and discussed in Section RR – Resources Required. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2, 6.3, and 6.4 aircraft weaponization R&D efforts are listed in table AW–B.

TABLE AW–B
AVRADCOM's AIRCRAFT WEAPONIZATION FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) OF COMMAND SCHEDULE FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78	
		R&T LABORATORIES	D&E DIRECTORATE
6.2	1L262201DH96	1227	
6.3	1L263206D043		733
6.3	1L263206D044		308
6.4	1H264202DL62		5578
6.4	1H264202D133*		11650

*The XM788/789 30mm ammunition development task under this project is managed by the AAH PM.

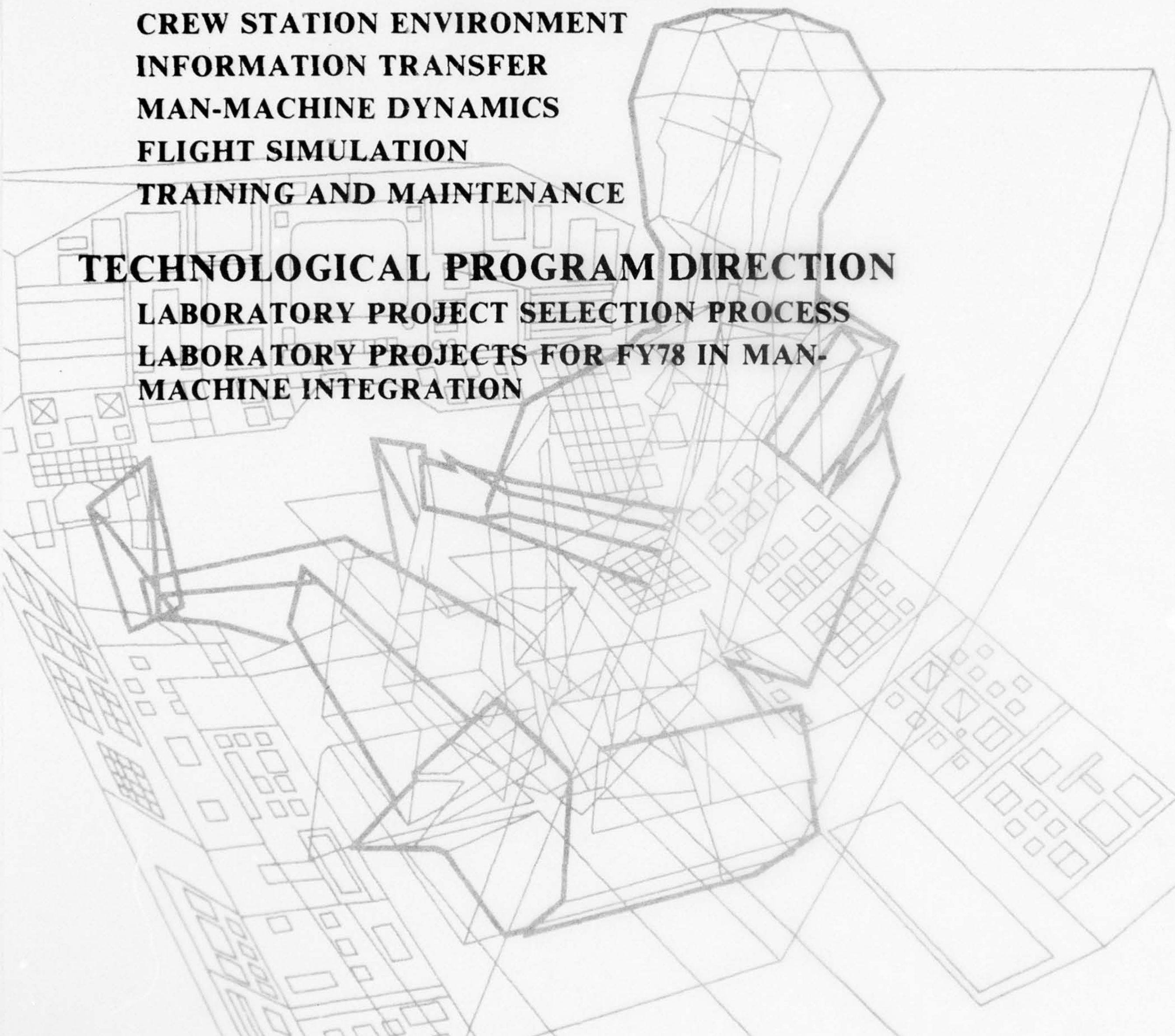
INTRODUCTION

TECHNOLOGICAL DISCUSSION

AIRCREW WORKLOAD QUANTIFICATION
CREW STATION ENVIRONMENT
INFORMATION TRANSFER
MAN-MACHINE DYNAMICS
FLIGHT SIMULATION
TRAINING AND MAINTENANCE

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS
LABORATORY PROJECTS FOR FY78 IN MAN-MACHINE INTEGRATION



INTRODUCTION

Man-Machine Integration, dealing with the engineering techniques and procedures for addressing operator requirements during system development, has surfaced as a strong technology development concern within AVRADCOM with a corresponding active R&D program. The previous title of this section, Human Factors, was changed to Man-Machine Integration to more accurately describe the effort. Although the Plan reflects human factors problems in Army aviation generally and deals with topics falling within the mission areas of numerous Army agencies, the intent is to cover the basic concern of AVRADCOM; that is, engineering technology in the human factors discipline is a useful and needed effort for aviation system integration. Man-machine integration refers directly to the engineering portions of the broader human factors discipline. As such, the material in both the technological discussion section and the program section has been extensively reorganized and revised.

In Army aviation, the human factors discipline can be described as a point of view, a technology, and a process. For current and foreseeable weapons systems, the basic limits on system performance are imposed by the men in the loop rather than by the capabilities of the system machinery. In general, technological advances have imposed increasing demands on system operators in the skill with which they employ their sensory, mental, and motor faculties. Currently, the personnel costs associated with having and using weapons systems exceed hardware costs, and this trend is growing steadily. Recognition of these basic realities and a determination to apply appropriate problem solving is the fundamental human factors *point of view*. The human factors *technology* consists of an extant scientific and technical body of knowledge, as well as the procedures and facilities for its continued expansion. Although its formal history is short, its volume is extensive and its diversity is exceeded only by that of the potential users' problems. The human factors *process* is one in which organizational policy and procedures are marshalled to ensure that results available from technology are fully utilized in the development and use of weapon system equipment.

Army aviation has set high goals for itself in its determination to adapt the next generation of aircraft to new mission requirements posed by night and all-weather operation, terrain flight tactics, and operational capability in mid-intensity threat environments. These requirements will call for a new level of sophistication in Army equipment. The challenging demands placed on flight and ground crews will certainly be unique and may prove to be more difficult than any other aviation assignments in the history of flight. Success in meeting these objectives will positively require departures from conventional helicopter design concepts. Man-machine integration can play a vital role in achieving this success by capitalizing on the human factors technology now available: by skillful allocation of resources and effort to fill present technology voids with shrinking research funds; and by innovative application of management skills to streamline the human factors process and make it more effective.

Human factors efforts span all phases of the system development process from research and development to test and evaluation. Throughout, the objective is better system performance as a result of good man-machine integration. Effectiveness in this process requires relevant research, sound design and development methods, proven engineering criteria, and valid test or demonstration procedures. The subdisciplines discussed below are one way of partitioning the interrelated areas in which technology base development can provide coordinated progress in the RDT&E process. Aircrew workload quantification refers to methodology and descriptive investigations into the fundamental processes of human behavior in performing aircrew duties. Observing, recording, measuring, modeling, predicting, and assessing aircrew performance are discussed in terms of new, more effective research and engineering methods. The Crew Station Environment section covers development and engineering requirements associated with aspects of the cockpit man-machine interface which are static in nature. It includes anthropometry, control-display layout, visibility envelopes, environmental stressors (noise, heat, vibration, lighting) and the long-term effects of sustained crew duty. Man-machine interactions which are dynamic in nature are discussed in the two following sections, Information Transfer and Man-Machine Dynamics. They cover display, control, information requirements, control dynamics, and other general issues in cockpit equipment employed by the aircrew. This area offers the greatest opportunity for hardware innovations, for cost control, and for enhanced system performance. The next section discusses two basic issues in flight simulation: determining the visual, motion, and other design requirements

for an advanced flight simulator for system research and development, and developing the specific R&D plans and strategies for its use. The final section, Training and Maintenance, discusses the prospects for system design procedures with the stated objective of controlling training, proficiency, maintenance, and other system-related personnel costs.

This Man-Machine Integration Plan identifies current problem areas and qualitative improvement goals for R&D achievement in several time periods. The objectives and the program elements of the plan are summarized in each subsection of the technological discussion and will permit additional specific goals to be defined. Priority in the development of specific projects in support of the program goals will be assigned to those efforts for which (1) the need is greatest (considering especially the timing of systems now in development); (2) man-machine integration contributions are clearly achievable in useful form; and (3) the maximum resultant payoff in improved system effectiveness can be obtained. Emphasis will also be placed on objectives most directly related to night and all-weather operations and to terrain flight operations.

TECHNOLOGICAL DISCUSSION

AIRCREW WORKLOAD QUANTIFICATION

For Army aviation, the gaps in human factors technology that most significantly limit its usefulness are basic problems in measurement, assessment, and prediction of human performance, and in identifying the relationship between operator performance and overall system effectiveness. The central role of pilot and aircrew performance in achieving maximum system effectiveness is well recognized. Most accounts deal with system limitations due to pilot and aircrew performance in terms of an operator workload or taskload approach. Although many methods are currently employed for describing, assessing, and dealing experimentally with pilot and crew performance, all of them are lacking in either objectivity or generality, or both. These limitations have prevented the full development and use of task-loading and other systematic approaches in both general and quantitative forms. As a secondary effect, they have delayed efforts to relate crew performance variables to system effectiveness.

Since the basic methodological tools have not been adequately developed and standardized, downstream engineering procedures and criteria for systematic man-machine integration have not matured. The system integrator's engineering capability in man-machine integration depends mainly on precedent, extrapolation from prior successful designs, and rule-of-thumb criteria. When new or more demanding mission requirements converge rapidly, as in the present requirement for all weather terrain flight and mid-intensity threat environment survivability, and when component hardware technology advances rapidly as in the present case of control and display equipment, the trial-and-error man-machine integration process can be overwhelmed. The complete solution to this set of problems should treat both the current engineering process technology voids and the more fundamental problems of basic methodological tools needed to develop general systematic engineering procedures and criteria.

Improvements in aircrew workload quantification are required to standardize the measurement of crew performance in operational settings, to provide full objectivity of measurement where possible, and to improve the uniformity of subjective measurement procedures where these remain necessary. The main goal is the identification of objective and quantitative measurement procedures that can be widely applied to different crew stations, tasks, and missions; and to equipment, mockups, and simulators in varying degrees of completeness. This capability will provide a common basis for correlation and evaluation of measurement data, and will permit better comparison and interpretation of experimental results.

Ultimately, basic improvements in the tools of aircrew workload quantification will permit the development of full and systematic theoretical accounts of man-machine interaction. Translated into useful results, this will permit the identification of machine design variables and properties that can contribute to efficient human performance and ultimately optimize system effectiveness. Tradeoffs between system cost and system performance can be specified directly through the mediating variables measurable as human performance parameters. The general and specific effects of stressors (such as fatigue, high task-loading, combat-induced emotional states) and environmental conditions (such as heat and noise) can also be accounted for in a useful and systematic way. It will be possible using these new methods to compare the relative payoff in system performance from any proposed change in the man-machine interface, such as

the addition or deletion of specific equipment, changes in equipment layout, changes in training or operational procedures, and improvements in environmental control systems. The need for these capabilities is most acute in the engineering process associated with cockpit and crew station design, but the above remarks also apply to maintenance, servicing, and other areas in which men serve as system elements. The problems are general and can be seen in each of the more specific problem areas detailed in the sections that follow.

Although considerable success has been achieved in the development of mathematical representations of other components of aircraft systems, modeling of pilot and crew performance has not produced comprehensive and useful results. Successful mathematical models of pilot and crew behavior are needed in forms useful for stability and control or handling qualities analysis and simulations, for display and information processing analysis of display design and implementation requirements, and in forms that will identify marginal effects in order to account for individual variability of pilot and crew behavior and deviations from optimum designs. Improvements in this area can eliminate the present dependence on small nonrandom samples of actual human performance in the evaluation of new aircraft system concepts. They can also provide the basis for computerized task analysis and other useful research and development modeling aids. AVRADCOM has an active research program in this subdiscipline conducted mainly by R&T Laboratories (AVRADCOM). Coordination is maintained with other agencies active in the area.

The objectives of the R&D program in expanding the capabilities of aircrew workload quantification are detailed in chart MI–I.

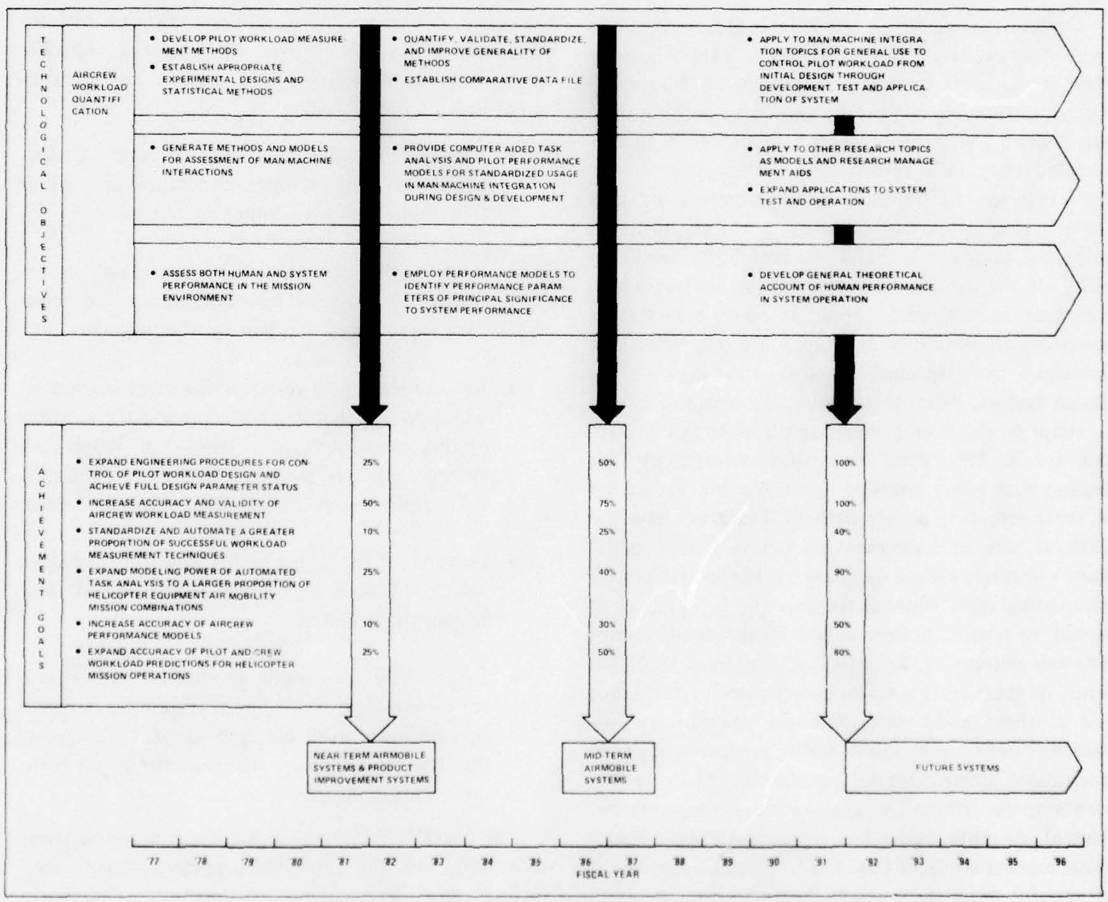


Chart MI–I. Aircrew workload quantification objectives summary and achievement goals.

CREW STATION ENVIRONMENT

Man-machine interactions can be roughly divided into static and dynamic categories. This section deals with those aspects of aircraft crew station design and environmental control involving relatively static man-machine relationships. These factors include for example, cockpit anthropometry, accessibility of controls and displays, egress provisions, seat support and retention provisions, external visibility, and environmental factors such as lighting, noise, vibration, and other life support control provisions. Human factors technology has been most successful in developing design guidelines, principles, and man-machine integration procedures in this area. Continued development is needed, however, to meet the requirements of new and more demanding mission capabilities and to allow the efficient utilization of new concepts and equipment in crewstation design.

Currently available design criteria are often stated only in qualitative terms or are in the form of a single value design goal. In most cases, the research supporting these findings has been oriented to seeking optimal values for a given factor, with other factors sampled only in a narrow range. Thus, the interactions between different static design factors, and also the marginal effects of deviation from an optimum value, are poorly defined. The adaptability and flexibility of the human operator (the properties which are most heavily relied upon in his role as system operator) allow him to accommodate relatively large deviations from optimum in most of the crew station design factors. When this occurs, the operator is said to adapt to the nonoptimal condition or to compensate for it. This often diminishes his capability for dealing with other stressors and tasks, but the nature of these effects is poorly defined. Designers have the difficult task of balancing competing design guidelines and single-valued design goals in the overall task of creating crew stations for specific missions. They would be much better served if the relationships between competing design objectives were stated in terms of their mutual effect on operator performance and if they could determine the operator performance "cost" associated with compensating for inadequate environmental conditions. Such refinements in the criteria for temperature, noise, vibration control, visibility, and other static crew station design requirements are now required to permit the creation of suitable crew stations for the expanded operating envelopes and mission requirements of the Army's future aircraft.

New developments in other technologies are also changing old concepts of crew station design. Refinements in static crew station design criteria are needed to permit the fullest possible utilization of these developments in effective ways. New materials, sound suppression treatments, environmental control devices, lighting equipment, display and control equipment, improvements in seat comfort, retention and protection, and many other developments affect the various static crew station factors. Criteria for crew station static factors must be made to keep pace with these advancing technologies.

As the relationships between significant crew station environment factors are defined, and as their mutual effects on crew performance are better established, specific programs addressing long-standing crew station deficiencies can be undertaken. The long range objective is to obtain maximum system effectiveness by providing crew station designs that permit optimal human performance. Crew comfort or convenience, *per se*, will no doubt be improved; but this is a side effect rather than the objective. Specific program goals in improving the crew station environment include the following:

- Reduce the adverse effects on crew performance of noise, temperature, humidity, vibration, and other environmental stressors.
- Reduce the adverse effects on crew performance due to seat, restraint, armor and other crew furnishings, and personnel equipment.
- Resolve the controversial issues involving red vs. white cockpit lighting concepts and the relation of this and other aspects of cockpit vision provisions (glare, reflections, etc.) to specific mission requirements and to pilot night vision aids.
- Provide for the higher agility and control power associated with high-performance aircraft and terrain flight tactics.
- Establish requirements, provisions, and criteria for crew escape and ejection systems as technology becomes available; provide suitable egress, ditching, and crash protection criteria for basic crew station designs.

The overall objectives of man-machine integration technology in the crew station environment area include the development of matured systematic accounts relating design factors, operator performance, and mission requirements. Achievement of

this objective will permit more effective determination of crew requirements and crew station configurations for specific missions, and will permit more efficient allocation of functions between crewmen and between man and machine for identified mission objectives. AVRADCOM conducts anthropometry standards development and R&D on the use of mock-ups in system development in this subdiscipline. Much of the Army's active research and development on crew station environment requirements is conducted by other agencies. Active coordination with these agencies is maintained to insure that research and technology outcomes are fully applied in the man-machine integration process.

R&D program objectives related to crew station environment factors are presented in chart MI–II.

INFORMATION TRANSFER

This section as well as the next section, Man-Machine Dynamics, deals with those aspects of crew station design involving relatively dynamic man-machine relationships. Included are the factors and processes associated with the use of displays such as information transfer, processing, and evaluation; the use of controls for aircraft attitude and flight path adjustment; and the use of all other crew station equipment requiring attentive interaction between operator and machine. In the effort to efficiently utilize the human operator's capabilities and to adequately accommodate the human operator's limitations, the dynamic man-machine interface factors offer the most promising opportunities and the severest challenges to human factors technology. The long range objective of broad systematic progress in man-machine integration will require consolidation and extension of the work discussed for these subdisciplines and for the subdiscipline entitled Aircrew Workload Quantification. In the immediate future, specific adavances in a number of individual man-machine interface problems are both possible and needed for systems now in development.

The number of possibilities for promising man-machine integration research is quite large, and theoretical efforts to date do not display a unifying cohesiveness. Because of this, a research strategy is

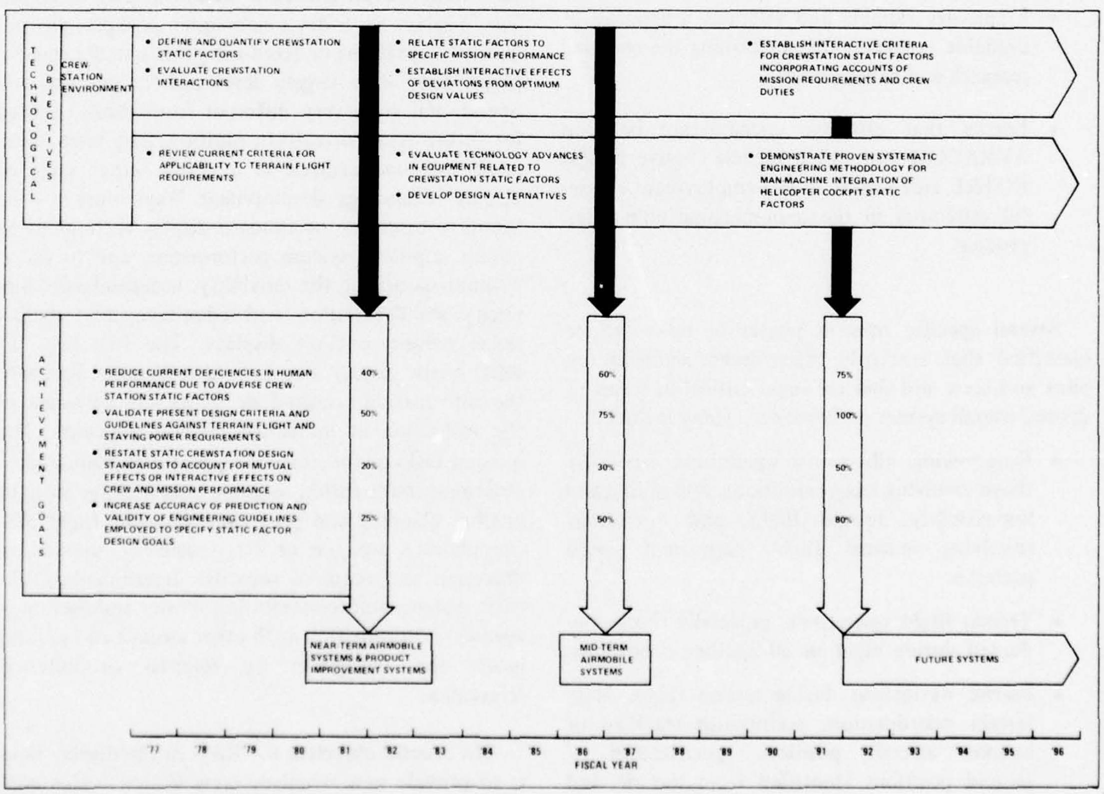


Chart MI–II. Crew station environment objectives summary and achievement goals.

required for near-term efforts to emphasize current needs and most-promising paths. Initial efforts under the strategy adopted here will:

- Respond to worst-case mission phases and tasks. Development and research will concentrate on man-machine integration problems in these subdisciplines for which desired system performance is currently most difficult to attain.

- Emphasize the application of man-machine integration principles and research approaches already known to be effective and productive.

- Ensure broad consideration of the usefulness of new equipment, new design concepts, and new capabilities provided by advances in technology in other areas.

- Employ the best available behavioral research methods and tools, and incorporate advances in methodology wherever possible.

- Emphasize flexible and efficient utilization of available resources for performing the required research and development.

- Ensure that effective coordination between AVRADOM and other agencies active in this RDT&E area results in full employment of useful outcomes in the man-machine integration process.

Several specific mission phases or tasks can be identified that currently place severe demands on pilot and crew and that are most critical in terms of desired overall system performance. These include:

- Rotary-wing, all-weather operations, especially those involving icing conditions, low-ceiling and low-visibility, terrain flight, and operations involving unusual flight path and speed patterns.

- Terrain flight operations, especially those conducted during night or all-weather conditions.

- Precise navigation during terrain flight. Map-terrain coordination, continuous tracking of current aircraft position, specification of ground positions identified from the air, and location of desired map points on the ground are all very difficult crew tasks.

- Target detection, recognition, identification, localizing, ranging, and handoff, especially in relation to evasive aircraft maneuvers.

- Weapons selection and delivery, including aiming on-board weapons and controlling fire from other sources.

- Rapid and efficient cargo handling in precise acquisition and delivery operations.

Initial efforts will concentrate on finding practical solutions and simple equipment to permit the successful performance of these mission phases.

The information transfer subdiscipline focuses on problems in the information and display area for crew station design. Close parallels exist in the controls area. The required information for a given mission is often difficult to specify and many requirements vary with mission phase and mission type. Information requirements can be implemented by displays in many ways and progress in the various display areas is occurring rapidly, presenting the possibility of radically new cockpit and crew station display concepts. The displays in today's helicopter cockpits are primarily adaptations of fixed-wing instruments and displays. They were largely developed for missions and operational roles very different from those planned for future army aircraft; in addition, they were developed and standardized at a much earlier stage of display technology development. Ways must now be found to capitalize on modern display technology to obtain improved system performance, and to do so without sacrificing the reliability, independence, simplicity, standardization, and redundancy that characterize present cockpit displays. The first goal for R&D in the display area is to identify more precisely the information required by pilots and crewmen in the execution of individual mission segments. The mission tasks or functions that should be evaluated to determine information requirements include in-flight mission planning and progress evaluation, flight profile phasing, weapon or cargo delivery, opposition detection and required response determination, aircraft systems status monitoring, power and fuel management, coordination with other aircraft and ground units, and navigation by internal or external references.

The second objective for R&D in the display field is to provide new wholistic crew station design concepts and methods that will display the required information efficiently and effectively. The objective

is to achieve more accurate, more reliable, and faster information transfer by providing displays that are easier to use and interpret. Information can be displayed in combined forms and in improved formats to achieve reductions in scan and interpretation times. Concepts such as the pilot-manager approach for highly automated equipment, and the attention management approach for less complex systems, should be fully explored. The most significant current problem area is high visual task-loading encountered in contour and NOE pilot tasks. Visual displays also pose difficulties for other operations requiring external visual attention and for night operations in which visual dark adaptation is required or pilot vision aids are involved. Reductions in visual task-loading, better management of limited pilot and crew visual attention, and nonvisual displays should receive careful attention.

One of the most promising approaches for improved man-machine integration is the possibility of effectively combining displays with one another and with control devices. Sensible and appropriate combinations of displays can greatly improve information transfer by eliminating mental effort. similarly, combinations of related displays or displays and controls can make it possible to perform more complex functions. Head-up displays (HUD) can permit, for example, both navigation and attitude control functions to be performed simultaneously. Displays can now be created that integrate the information required for a variety of specific mission functions, that efficiently use available time and capabilities of the pilot, and that more directly translate pilot decisions into control inputs. Developments in the display field that should be evaluated for applicability to Army mission requirements include head-up displays; helmet-mounted displays; and CRT devices for display of FLIR, IR, radar, and LLTV, as well as altitude, navigation, and system status or warning signals. Advanced electromechanical devices for integrated horizontal and vertical situation displays should be explored for application to Army requirements.

Program objectives for R&D in this subdiscipline are presented in chart MI–III. An active research

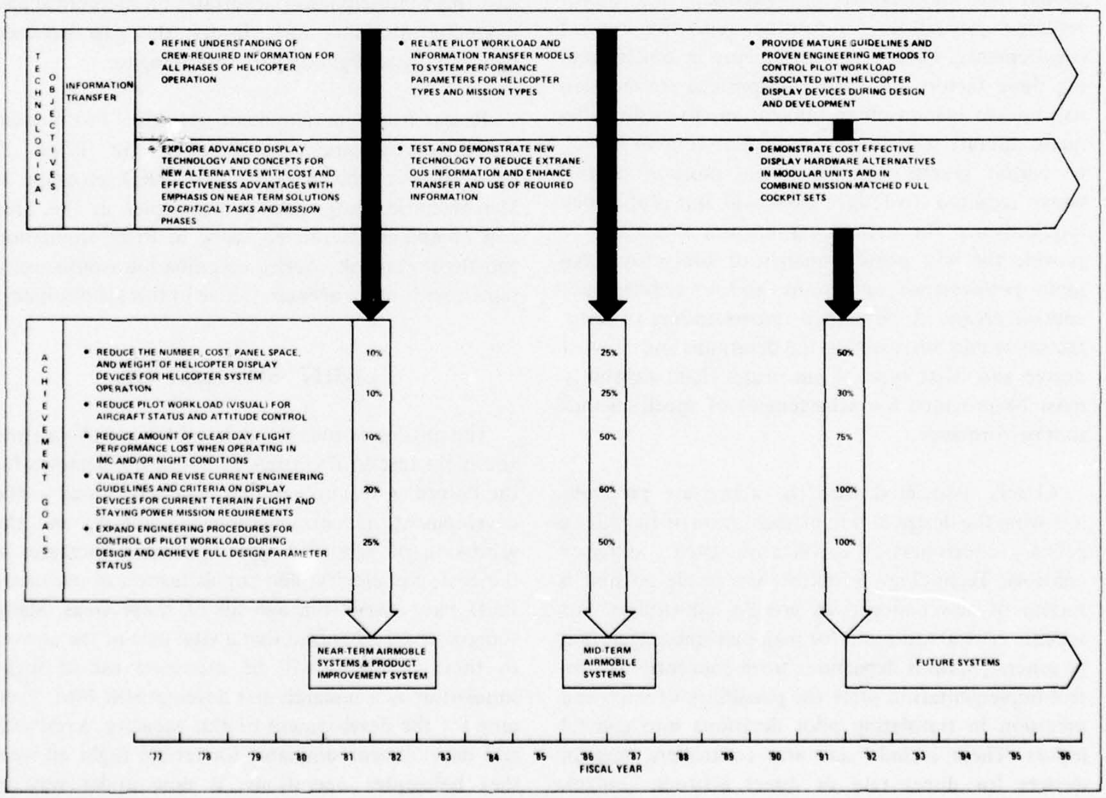


Chart MI–III. Information transfer objectives summary and achievement goals.

effort is maintained in this area by AVRADCOM and the effort includes coordination with other R&D units performing related or complementary programs.

MAN-MACHINE DYNAMICS

This subdiscipline broadly covers the control portion of cockpit man-machine integration in the same general way that the previous subdiscipline deals with displays. In many ways the division into two sections is an artificial arrangement for the sake of easy discussion. In both research and development, and in the system integration process, the two must be treated simultaneously as an undivided topic.

In contrast to conventional aircraft, rotary-wing and V/STOL aircraft dynamics pose difficult design problems in specifying handling qualities, stability characteristics, control power, and control implementation. Efficient use of the pilot's capabilities requires a balanced design in this area. He must have the full range of aircraft response capability at his disposal for use when necessary. At the same time, the aircraft should not monopolize his attention and motor response capabilities for routine, repetitive control requirements. General improvements in understanding these factors and their relationships are required to improve man-machine integration, to ensure adequate aircraft responsiveness to pilot control inputs, to permit precise flight path and position control where required, to reduce pilot skill and proficiency requirements for demanding mission segments, to provide the best possible margin of safety for maximum performance operations, and to reduce pilot control errors. A developed understanding of these factors would also assist in the determination of what degree and what type of automatic flight capability must be provided for achievement of specified mission performance.

Closely associated with the above are problems involving the design and implementation of the pilot's primary controllers: the collective, cyclic, and yaw controls. Technology advances have made possible a variety of new concepts in primary controllers. For specific critical tasks and for man-machine integration in general, various departures from conventional control implementation offer the possibility of improved precision in translating pilot decisions into control inputs. These include side arm controllers, manual devices for direct rate or direct attitude control, fly-by-wire systems, including fly-through autopilot designs, controls integrated to provide combined pitch-roll-yaw-altitude control, and controls incorporating tactile displays, as well as the more conventional accessory stick-grip switch arrays. Suitable implementations of these concepts or other control innovations could provide increased control precision; reduced pilot manual task loading; reduced effort, response time, and error rates; and reduced unintentional mixing of roll and pitch commands.

Such control system improvements are the direct counterpart of information transfer gains which can result from display integration. It should also be mentioned that advanced understanding of man-machine dynamics can help designers avoid overly complex control systems. By knowing the degree and type of control-system pilot aids needed to achieve specific mission performance, balanced designs can be selected which eliminate unnecessary cost, complexity, and unreliability. One of the long-term objectives of this subdiscipline is to provide the information on pilot control performance and capacity needed for general solution of this problem. Although emphasis is placed on the aircraft hardware technology related to man-machine dynamics by flight controls specialists, this subdiscipline concentrates on theoretical and modeling accounts that bridge the gap between behavioral and flight control technologies.

Research and development objectives in the man-machine dynamics subdiscipline are listed in chart MI–IV. The AVRADCOM R&D program in Man-Machine Integration covers topics in this area and complements related work in flight simulation and flight controls. Active coordination is also maintained with other agencies active in this subdiscipline.

FLIGHT SIMULATION

The mission requirements trend toward all-weather and night terrain flight has extensive implications for the nature of technology base research as well as the development of new engineering methods and the validation of proposed system designs. Increases in the cost, complexity, and sophistication of necessary R&D have swept through all of these areas. Many sources have recognized that a vital part of the answer to these problems will be increased use of flight simulation as a research and development tool. Planning for the development of this capacity, a research and development simulator for terrain flight all weather helicopter operations, is now under way in AVRADCOM. When an effective capability to simulate nap-of-the-earth helicopter operations and other

current mission requirements is finally available, significant issues in both technology base R&D and in system development support can be resolved. Simulation will provide fundamental knowledge in man-machine integration, flight controls, and other basic technologies as well as trade-off information for use in system design. It can be employed to originate, demonstrate, and validate system design methods and engineering criteria. The benefits will include a capability to evaluate system and subsystem hardware before significant Army commitments have been made. It will permit the development of a new spectrum of cockpit and control system hardware, new research and engineering methods, and validated criteria and test techniques all matched to the new and demanding air mobility mission environment.

The speed, safety, and economy with which these benefits can be realized by strategies based on simulation R&D are the positive side of the picture. But an advanced research simulator with high versatility and sufficient helicopter mission modeling power to permit valid forecasts of real system performance is itself an expensive and complex system. Current problems center on the design and development of a new simulator which will meet the R&D objectives, and on the development of specific plans, procedures, and strategies for its employment. To a major degree, the visual display system performance requirements for terrain flight helicopter mission simulation are unknown. Field of view, detail resolution, scene detail content, and dynamics for simulating NOE flight and mission tasks remain to be determined. The best technology for such a facility (e.g., TV, terrain models, computer imagery, laser-based displays, etc.) is also not immediately evident. Other design choices in terms of motion system performance, computer control equipment and cockpit versatility remain to be determined as well. Resolution of these questions may require human factors research on sensory and orienting mechanisms for aircrew tasks.

The detail design of a research simulator also depends heavily on the purposes to which it will be put. This calls for extensive planning and review of potential research to establish topics, variables, subjects, hardware, and software to be studied, all of which impact simulator system requirements. This

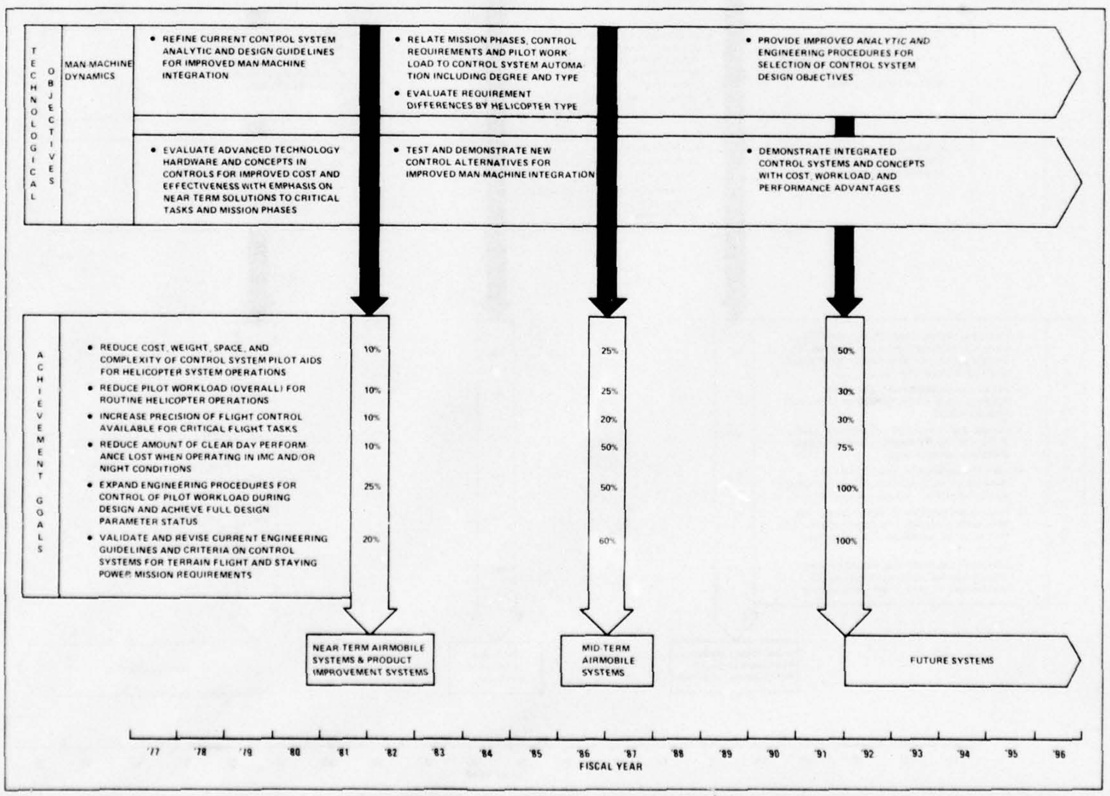


Chart MI–IV. Man-machine dynamics objectives summary and achievement goals.

effort is now under way in the areas of flight control technology and man-machine integration. Both of these disciplines will be major users of the new capability. Similar planning will need to be performed to cover system engineering and product manager support applications of this new R&D capability.

If utilization of flight simulation in R&D is to be efficient, it should be conducted on a systematic basis. This calls for the development of research procedures, uniform test strategies, standardized experimental designs and data recording systems that preserve useful data in forms suitable for between-test comparisons. Methods must also be found to explore and define the extent of each simulation's modeling power. This is the general case of the training simulator's validation problem. For R&D the question is one of establishing predictive validity for the simulator test results. Also, since there will always be hardware or mission tasks for which any given simulator's modeling power is insufficient, it may be necessary to employ one simulator to generate the requirements for another more complex or more specialized simulator.

Within AVRADCOM these objectives are now the focus of an extensive program to develop flight simulation for R&D. The man-machine integration objectives falling in the flight simulation subdiscipline are summarized in chart MI–V.

TRAINING AND MAINTENANCE

System design affects training and maintenance requirements because these are largely built-in when systems and equipment are originated. The costs and importance of these requirements are principal factors in the operation of Army aviation systems. Deficiencies in either directly affect flight safety and

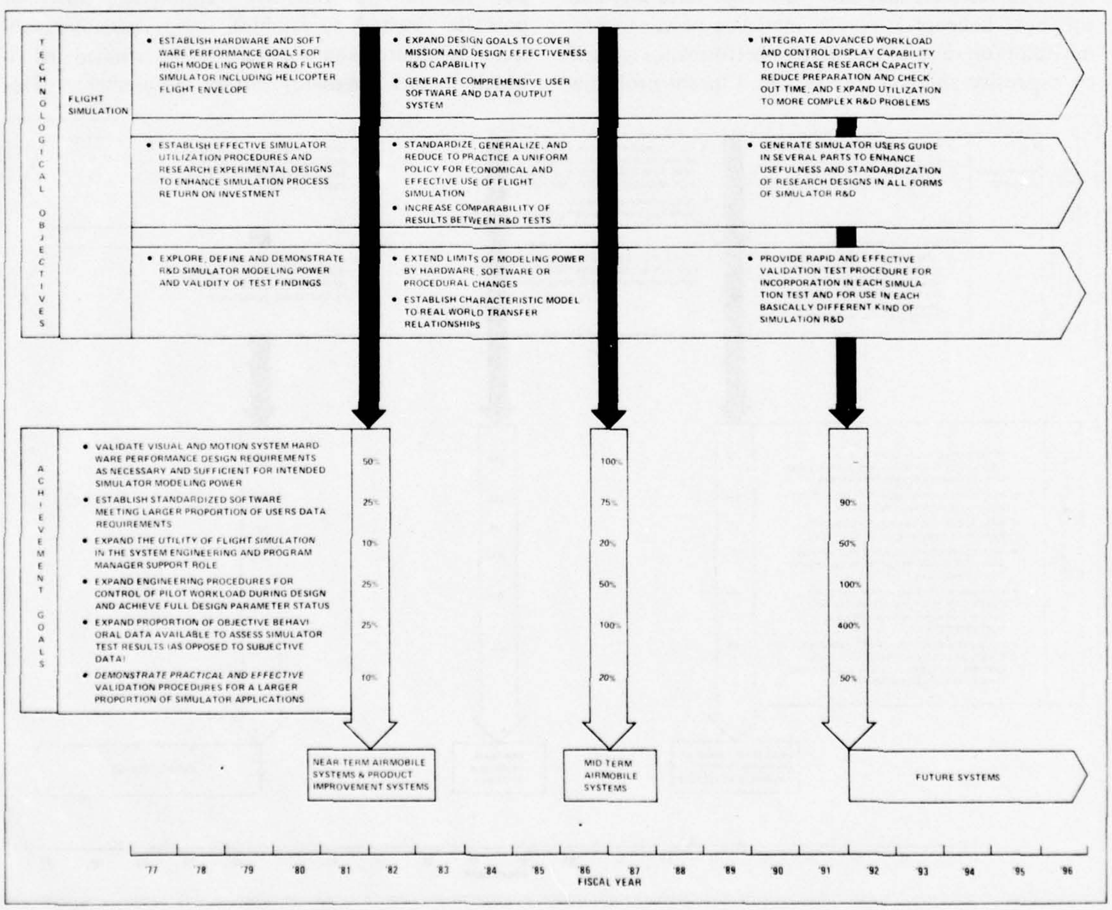


Chart MI–V. Flight simulation objectives summary and achievement goals.

operational effectiveness. In both areas the significance of potential improvements requires continued research efforts to increase efficiency in the use of manpower. The objectives of R&D efforts in this area are to reduce training and maintenance requirements, to provide improved procedures for performing training and maintenance, and to increase the effectiveness of training and maintenance aids.

In the area of flight crew training, Army efforts have pioneered the use of simulation and other up-to-date techniques. R&D efforts are required to extend the benefits obtained by these techniques and also to develop crew station designs and aircraft operating characteristics that minimize flight time for training and proficiency. But training also encompasses ground crew personnel who service and maintain aircraft systems. Here more than anywhere, improved aircraft design procedures, the effective use of built-in test equipment, better job aids, and consideration of man-machine integration aspects of maintainability and accessibility can minimize maintenance training requirements. Because support personnel outweigh aircrews in training costs, this is the highest pay-off area for R&D on reduced training requirements. The same improvements can be expected to result in better maintenance, performed when required and done correctly the first time. This will result in improved maintenance and service operations in forward areas where combat effectiveness is directly influenced. The R&D program concerned with human factors in servicing and maintenance will have a strong interface with developments in reliability, maintainability, diagnostic, and ground support equipment.

At the present time R&D objectives in training and maintenance are addressed only indirectly by the AVRADCOM effort in man-machine integration. Active coordination is maintained with other Army agencies that do have research efforts in the area; and the basic objectives are of direct concern in other AVRADCOM programs on reliability and maintainability, and on diagnostic and ground support equipment. In the engineering process, training and maintenance criteria provide important design objectives for all system developers. Achievement goals for this subdiscipline are listed in chart MI–VI.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The project selection process philosophy and elements are presented in the Technology Introduction section of the Plan. This section applies that process to the man-machine integration discipline. The OPR is not an objective of the Plan, but is provided to show the procedure used by the Laboratory in the selection of programs within a discipline as constrained by the Army's R&D budget.

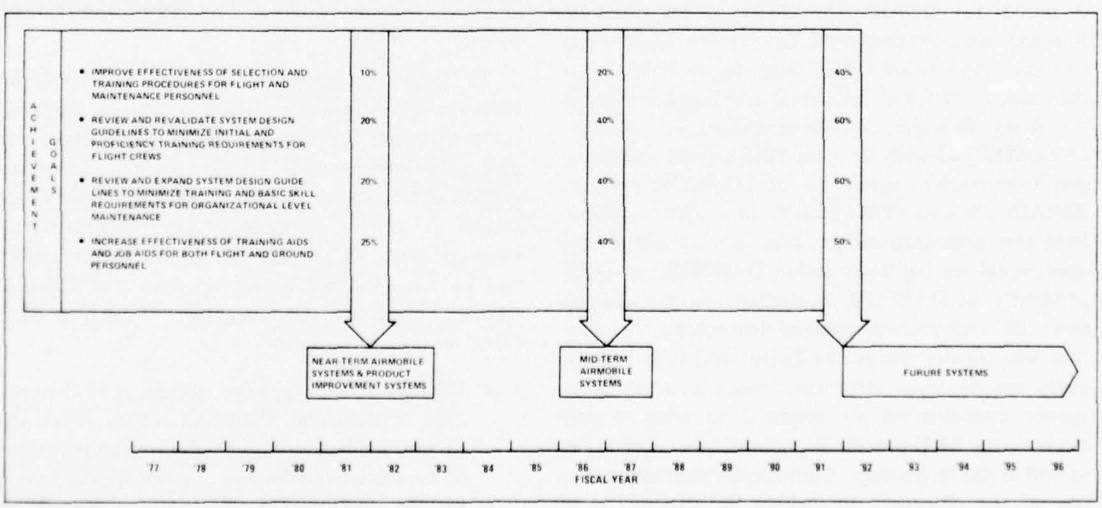


Chart MI–VI. Training and maintenance achievement goals.

PROGRAM STRATEGIES

In each of the subdiscipline areas, special emphasis must be placed on obtaining the maximum results from research efforts by ensuring that all of the available research methods and tools are fully exploited. The capabilities of new procedures, better experimental designs, and innovative test and measurement schemes must not be overlooked. Modern developments in the behavioral sciences can provide improved observation, recording, and analysis of human performance. Related developments in mathematical modeling of behavior, instrumentation for recording, and electronic data processing of results must be comprehensively employed. Advances in film and video tape image acquisition, for example, offer the opportunity to significantly improve research methodology. Man-machine integration problems require (and can significantly benefit from) increased use of simulation techniques and more extensive use of technology demonstration procedures. The use of mockups, dedicated aircraft in subsystem development, advanced field test concepts, and more complete testing throughout system and subsystem development can greatly expedite systematic progress in man-machine integration.

An important point of emphasis in the research strategy adopted here places importance on the efficient use of all of the Army's man-machine integration resources. Numerous organizations have an interest in and participate in aviation RDT&E in this field. Personnel and facilities are found in many locations. A partial list includes The Office of the Chief of Research and Development; the Human Engineering Laboratory; Aviation R&D Command, including both the Directorate for Development and Engineering and the Army Research and Development Laboratories (AVRADCOM) with its joint NASA-Army facilities; and Commodity commands of DARCOM such as MIRADCOM and CORADCOM. In addition, several field test organizations perform developmental and operational testing both within DARCOM and independently of DARCOM. Systematic progress in the many difficult problem areas of man-machine integration will require the most efficient and fully coordinated use of these resources. New efforts at interagency coordination are required to advance and improve the R&D process in man-machine integration as well as the technology. Coordinated management is one of the objectives in making the process more effective. The others are more specific goals in streamlining, updating, and improving the methods and practices used to incorporate man-machine integration technology into Army systems during development and procurement. Improved methods must be developed for system analysis, task analysis, workload prediction, determination of manpower and crew requirements, for the use of mockups and models, and for the development of test and evaluation requirements to verify that designs function as intended. Additional process-related methodology improvements will be developed in procedures for test and evaluation and in the effective use of specifications, standards, and other contract-related guidance documents.

An active R&D program is under way in four of the subdisciplines described in this section: aircrew workload quantification, flight simulation, information transfer, and man-machine dynamics.

OBJECTIVES

The main overall man-machine integration objective is the initiation of specific basic and applied behavioral research projects to fill the current technology gaps that most significantly impact operational mission requirements and system costs. Major problem areas concern high operator visual and auditory task loading during all types of terrain flying; visual requirements during night and adverse weather operations for flight, navigation, target acquisition, and weapons delivery functions; cockpit control and display requirements for the levels of man-machine integration required by the new spectrum of adverse weather, night and precision cargo operations; and the definition of simulation capabilities required to provide a useful simulator for engineering research and development.

The near-term program objectives for FY78 for these subdisciplines are established from the near-term quantified achievement goals listed in charts MI–I through MI–VI. The man-machine integration objectives are of two types: first, those which result in direct technology improvements; and second, those which improve prediction capability and produce indirect technology and cost improvements. The FY78 man-machine integration R&D objectives are as follows:

- Develop and expand the usefulness of the concept of workload. Pilot and aircrew workload or task loading should be elevated to the status of a research variable and engineering parameter by the development of reliable measurement procedures applicable to cockpit tasks in general. Standardized and general measurement

procedures should lead to accurate modeling and predictive capabilities.

- Initiate development of advanced visual, auditory, and other cockpit display devices to permit information transfer capability with reductions in visual and auditory task loading.
- Develop a computer-based heuristic model of pilot attention. The model should provide rule-of-thumb or figure-of-merit outputs concerning pilot workload based on cockpit interface properties and mission requirements inputs. Refinements of the initial effort should serve as a research tool leading to advances in engineering procedures for man-machine interface design.
- Obtain more complete data on visual information, task requirements, and stimulus properties prevalent in terrain flight operations, especially night and adverse weather operations. The stimulus conditions and visual task requirements of target acquisition for the characteristic range of mission conditions should also be more fully explored. The effort should lead to a summary of relevant data in a format suitable for describing and predicting visual information and performance requirements of aircrew members and visual display functions and requirements for visionic devices. The information should also provide a data base for the determination of simulation requirements for a research simulator to study terrain flight and night operation.
- Develop mathematical modeling capacity for computer-based task analysis. After selecting an appropriate software format, analytic, simulation, and field test data should be applied to the development of new program modules and subroutines for modeling air mobility missions to provide, first, computer aided and, later, fully automated task analysis as a cockpit development, preliminary systems design engineering tool.
- Develop design criteria for R&D flight simulator performance to provide adequate modeling power for the full operating flight envelope for all existing and planned helicopters. Simulation support research should address visual, motion, auditory, vibratory and cockpit design criteria, as well as software requirements for operator variables, utilization strategies and experimental design, and the difficult issues in verification of R&D simulator modeling power.
- In the area of man-machine dynamics, objectives are to improve analytic assessment capability of control system design suitability with respect to specific mission requirements. A related goal is the development of modeling capability for pilot multiple-control-task performance.

PROGRAM PRIORITIES

General. Table MI–A presents, in a prioritized listing, the man-machine integration technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to

TABLE MI–A
PRIORITIZED MAN-MACHINE INTEGRATION OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Aircrew Workload Quantification	I	• Cockpit Workstations	I	• Pilot-Crew Workload Reserve	I
• Flight Simulation	II	• Maintenance Workstations	II	• Night/Adverse Weather Operational Capability	II
• Information Transfer	III	• Support Facilities	III	• Flexibility of Utilization	III
• Man-Machine Dynamics	IV			• Personnel Costs	IV
				• Hardware Costs	V

facilitate the identification of major R&D program thrusts which support the near-term technical objectives of the Laboratory.

Technological Subdisciplines. The subdisciplines listed in table MI–A are the ones discussed earlier in this section in which the Laboratory currently conducts R&D programs. They include the following: aircrew workload quantification, which deals with human performance research, test methods, and modeling; flight simulation including both requirements and utilization procedures; information transfer covering display topics; and man-machine dynamics which treats control related issues.

Vehicle Subsystems. Vehicle subsystems are divided for consideration into aircrew workstations, groundcrew workstations, and support facilities. In this orientation, each aircraft worksite where maintenance is performed is regarded as a maintenance workstation. Emphasis on the man-machine interface is the main point of this breakdown. In the cockpit areas display, control, and communication equipment have the primary dynamic man-machine interface requirements; environmental control, personnel equipment, and crew station layout and anthropometry emphasize relatively static man-machine relationships. For maintenance workstations, component accessibility, visibility, and BITE or test and inspection provisions are the main concerns. The final category, support facilities, refers to software, hardware, and support facilities which are not aircraft components but which are required to complete the aircraft-based weapon system. Important elements include the weather and terrain information available during mission planning; the test stands, equipment, field manuals, and other ground equipment tools and job aids employed during maintenance; and the training equipment and facilities for both ground and aircrew personnel.

System Effectiveness. In the area of system effectiveness the usual speed-weight-power type of performance parameters have been deemphasized in favor of operability objectives which emphasize the quality of the man-machine interface. This is not to say that hardware performance is unimportant, but merely that it will be treated elsewhere; and that emphasis here is on the man-machine interface. The most important objective is to meet the mission objectives without creating excessive aircrew workloads. To provide for the contingencies of combat, some degree of aircrew mental and physical capacity should be available as a reserve over the normal mission requirements. Another important objective is to improve mission effectiveness in night and adverse weather conditions. Ideally, operational capability should be raised to the level of clear day operations and an expression of mission capability as a ratio of clear day effectiveness may prove useful in defining how well this goal is met for specific daylight and meteorological conditions. Flexibility of utilization refers to the vehicle's adaptability to varying tactics and mission assignments within its design role. Helicopter weapon systems should fully capitalize on the vehicle's inherent operational flexibility by providing rapid response times, easy shifts in mission types, adaptability to varying tactics and the ability to shift mission objectives even during mission execution. Overspecialization of equipment to achieve mission capability objectives can reduce versatility and this should be prevented in the man-machine interface design. The remaining system effectiveness objectives emphasize personnel and hardware costs. Systematic attention to each of these areas is warranted to obtain improvements in system performance and reductions in system cost.

Priorities. With reference to table MI–A, the man-machine integration subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I representing the highest priority. Since all of these categories and objectives are important, priorities should be regarded as suggestive rather than as absolute. Even with this degree of looseness in the assignment of priorities, several horizontal "tensor" relations can be usefully extracted from the table. Insertion of subcategories discussed above in each tensor can describe or suggest virtually every type of man-machine integration research and development effort with regard to approach, topic, and objective.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the man-machine integration R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 man-machine integration technology development program.

The major R&D thrusts pertaining to the human factors technology are:

- Develop behavioral measurement procedures applicable to the general case of man-machine interaction to characterize workload resulting from task and cockpit equipment combinations. Employ these procedures to model and predict workload to insure adequate mission workload reserves.
- Support the development and utilization of R&D flight simulation to reduce crew workload and improve night/all-weather mission effectiveness.
- Develop computer models of pilot and aircrew performance as research tools to relate cockpit workstation and task elements to aircrew workload and to aid in task analysis. Verify and improve the models to permit assessment of cockpit workstation and mission tasks on crew workload, night and adverse weather capability, and flexibility of utilization.
- Perform psychometric studies, simulation, and flight testing necessary to support development of visual, auditory, and other cockpit display devices to reduce sensory workload and to improve night and adverse weather capability.
- Assess visual information requirements and stimulus conditions encountered in night and adverse weather conditions to define man-machine dynamics and cockpit vision equipment performance requirements to provide mission flexibility, workload reserve, and night/adverse weather capability.

LABORATORY PROJECTS IN AVIATION MAN-MACHINE INTEGRATION

INTRODUCTION

This research began within the Army Research and Development Laboratories (AVRADCOM) in FY77 after coordination of plans and programs with other Army agencies involved with aviation human engineering and man-machine integration. Early attention was given to problem and approach definition for new efforts that have high payoff potential and represent aircraft development technology requirements specific to AVRADCOM mission areas and technology needs.

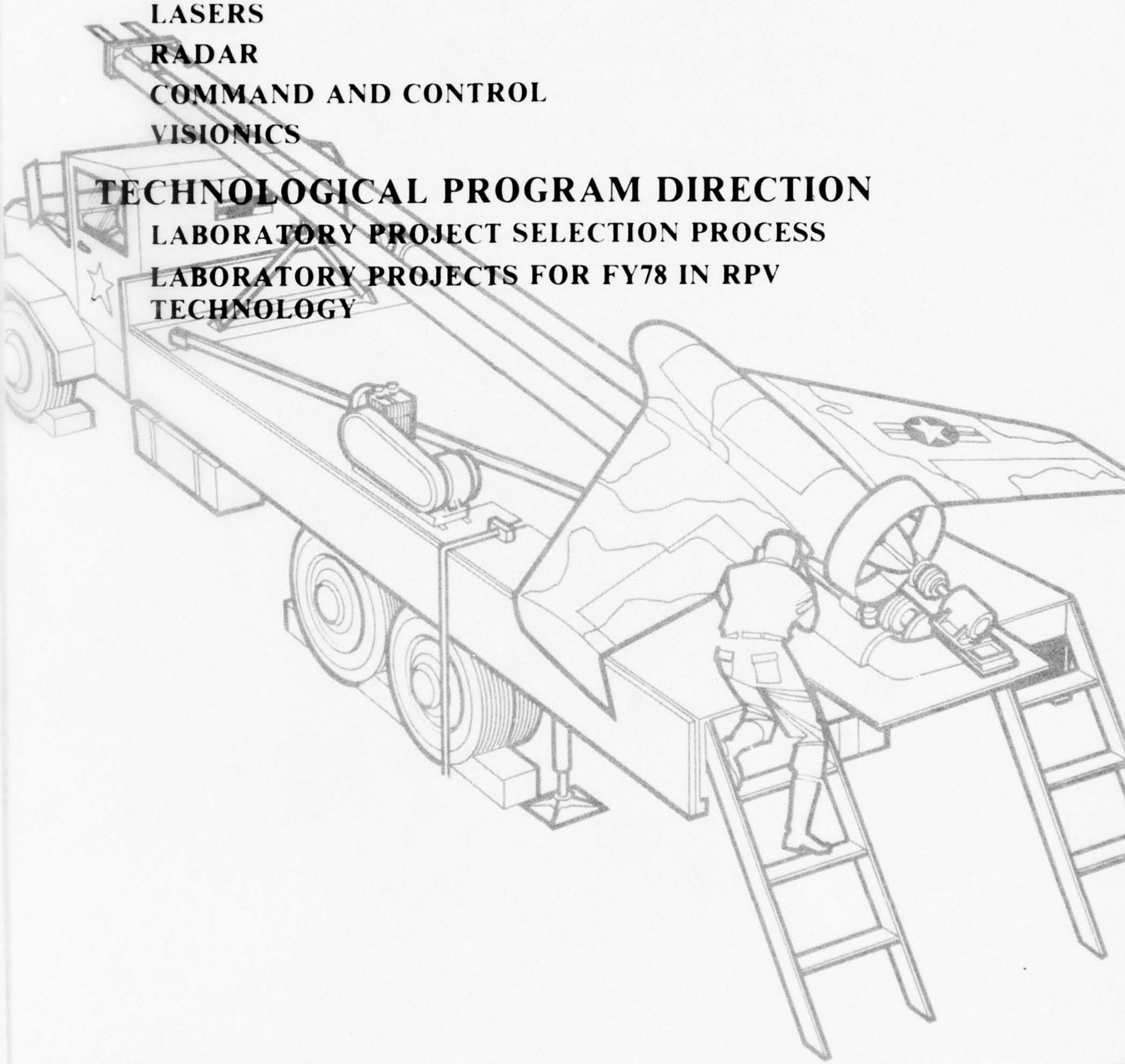
This is an exploratory development (6.2) effort conducted primarily by the Aeromechanics Laboratory, Moffett Field, California.

DESCRIPTION OF PROJECTS

Man-Machine Integration. Project 1L262209AH76-TA XI is an exploratory development effort to conduct a comprehensive and systematic program of behavioral research leading to improved methods and criteria for both design and test of Army air mobility vehicles and systems. The development of aviation man-machine integration technology will provide accurate prediction of design requirements and effective test verification procedures for Army airmobile mission requirements. The new methods, criteria, and understanding of man-machine interactions resulting from this technology will allow more effective use of aircrew skills and capabilities, improve man-machine integration, and will enhance the performance of operators as elements of airmobile systems. The approach involves coordinated analytical and experimental investigations utilizing laboratory tests, ground-based and in-flight simulators, mathematical modeling and model verification, and flight test investigations. Objectives are achieved largely through joint effort with NASA-Ames Research Center under the NASA-Army joint agreement. The efforts in man-machine integration complement and support related 6.2 projects in flight simulation and flight controls technology.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objectives of the man-machine integration R&D efforts as presented in the technical discussion are shown and discussed in Section RR – Resources Required. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 man-machine integration FY78 R&D effort is $163,000 and represents approximately 1 percent of the Laboratory's R&D funds (excluding Project 1L262201DH96 Aircraft Weapons Technology funds).



INTRODUCTION

Exploratory development efforts for Remotely Piloted Vehicles did not exist within AVRADCOM before FY76. Other laboratories, such as NVL and CSTA Laboratory, had mission programs that constituted a base for their RPV efforts, but AVRADCOM essentially did not. These baseline laboratory mission programs were consolidated and oriented toward RPV applications.

Many technological voids currently hamper the development of mini-RPVs (less than 200 lb) for military applications. The primary areas that need improvement are: air mobility, lasers, radar, command and control, and visionics. The term air mobility (as used here) encompasses many key disciplines necessary to the development of mini-RPVs – propulsion, launch and recovery, survivability, RPV configuration optimization, and structures. Laser developments emphasize rangefinders/designators that are smaller, lighter, brighter, and have duty cycles higher than lasers currently available. Radar is seen as a payload to extend mission capabilities into all-weather applications by providing fixed target enhancement, moving target indication, and high-resolution ground mapping. The fundamental deficiencies of currently available command and control equipment are that the RPVs must be operated in line of sight of the ground station, only a single RPV is aloft at a time, and little or no jamming protection is provided. The Army needs equipment to provide anti-jam protection for multiple RPV operations out of line of sight of the ground control station. Visionics efforts focus on two areas: TV and thermal imaging. Major emphasis is being given to reducing cost, weight, and bandwidth requirements consistent with RPV requirements.

TECHNOLOGICAL DISCUSSION

AIR MOBILITY

PROPULSION

Propulsion system technology for RPVs provides the mechanisms and processes by which the chemical energy in fuel is converted into forward thrust and/or lift and the required electrical energy to operate the RPV payload. The effect of the propulsion system technology on the aerial vehicle is profound. The performance, endurance, and reliability of the vehicle depends almost totally on the availability of the required power and how efficiently this power is converted to lift and/or thrust. The unique mission requirements of the RPV demand that the propulsion system deliver maximum horsepower/weight ratios, low levels of vibration to ensure adequate structural reliability, low noise and IR signature to reduce detectability and vulnerability, and low fuel consumption to ensure long range.

RPV propulsion systems are normally considered to include a powerplant (engine), an alternator (to convert mechanical energy from the engine to electrical energy to supply engine and payload electrical requirements), and a thrust producer (propeller or, for a rotary wing RPV, a rotor). However, market surveys of suitably sized powerplants, thrust producers, and alternators reveal the following:

- Currently available engines in the 5-60 horsepower range are unsuitable for application to RPVs because of vibration characteristics, reliability, high fuel consumption, high weight-to-power ratios, and high cost.
- Research of small propeller technology has not been conducted in the size applicable to RPV applications.
- Off-the-shelf alternators are too heavy and bulky for RPV applications.

To overcome these deficiencies, research and development efforts have been initiated to provide the propulsion system technology required to support Army RPV mission requirements. A propeller design optimization program was initiated in June 1976 to correlate small propeller design with large propeller design computer programs in order to provide a design tool for planned propeller fabrication and noise programs. Two 20-hp, mini-RPV engine demonstrator contracts were awarded in February 1977 to demonstrate the capability of using high production rate components (cylinders, rods, pistons, etc.) to resolve the problems of current off-the-shelf engines. Specific goals of the program are:

- 20 hp at sea level standard conditions, wide open throttle, 8000 rpm
- 0.8 lb/hp-hr SFC at WOT
- Two cylinder, two stroke cycle engine

- Weight excluding muffler and alternator not to exceed 1.2 lb/hp
- Life of 150 hours with no overhaul
- Low noise level and low vibration characteristics
- Cost not to exceed $750 per engine in production lots of 1000 engines
- Maximum utilization of off-the-shelf high production rate components

Alternator requirements are being defined and it is planned to modify the existing engine demonstrator contracts to include an integrated alternator as part of the overall engine system. This will reduce alternator development cost and will produce a more reliable cost effective system.

The near-term objective of the planned and ongoing research is to provide the Army with a suitable propulsion system to incorporate into the Army's first RPV aircraft.

The mid-term objective of RPV propulsion research and development is to develop advanced RPV propulsion systems designed specifically for the mission requirements of future mini-RPVs. Significant advantages in vibration, performance, and reliability should be possible with this approach. Primary emphasis will fall on the development of small piston engines and rotary combustion engines because they now represent the most promising alternatives. Designs will be subjected to extensive cost analyses relative to total life cycle cost (development, acquisition, and operation).

Long-term objectives of the RPV propulsion systems research and development will be to define RPV requirements and to investigate new concepts of propulsion systems to include turbofan, turboshaft, and other means of providing propulsion force. Research will be aimed at extending the operating envelope relative to altitude, speed, and environmental conditions.

LAUNCH AND RECOVERY

The Army is confronted with the necessity to launch and recover (L&R) sophisticated mini-RPV systems from unprepared sites in forward areas, it is evident that any equipment necessary to launch or recover such RPV systems imposes a burden on the units that operate these systems. Lightness, simplicity, mobility, and reliability are some of the modifiers that describe the improvements needed in RPV L&R operations.

Although the ideal RPV would be one that requires no L&R equipment, it must be emphasized that it is rarely possible to achieve such an ideal. Any airborne vehicle is sensitive to weight constraints and the tradeoff between complexibility, weight, and cost, and mission requirements is not decided by a single factor. Systems that result from these tradeoffs will have to be compromises between competing requirements.

The present launcher weighs about 800 lb and must be mounted on an M135 2-1/2-ton truck to be transported. The present recovery system is mounted on two 10-ton trailers and requires several pounds of equipment in the RPV in addition to the ground equipment. Projected system weight trends are shown in figure RV–1.

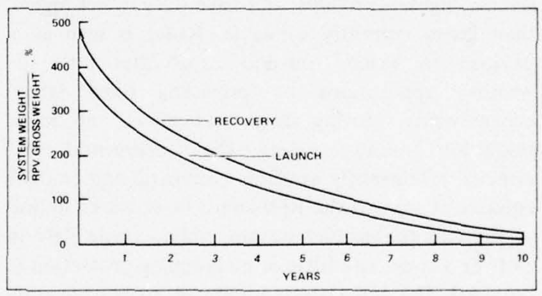


Figure RV–1. Forward area tactical systems.

The anticipated goals would be to reduce all these weights by a factor of 2 within 2 years and by a factor of 4 in 5 years.

Existing L&R systems are designs that do not fulfill the current tactical needs. Most launchers are some form of rail with a power boost (such as steam or compressed gas). They generate very large static and dynamic forces and the result is large, heavy structures to withstand the loads.

The 2-year time frame for a 50 percent reduction in the weight of a launcher is achievable through the use of more efficient structural materials and more efficiently integrated power boost for the RPV. A composite, filament wound, or tetrahedron structure for the basic launch frame should achieve this goal;

power assist from such items as superheated water or other chemical processes can probably surpass the 50 percent reduction.

Recovery is presently cumbersome and requires large areas for employment of vertical and/or horizontal nets, arresting equipment, and low-angle approach paths. In forward areas, this system would be easily located by the enemy, thus requiring much time and effort to set it up, maintain it, and camouflage it. Suitable areas for deployment are limited and operation in mountainous and swampy areas is infeasible.

Recovery systems can be designed that do not need all the present vehicular equipment, or do not need to be placed on the ground; however, any net recovery system requires structural supports and energy dissipation devices. Other devices have been analyzed in a recent study which shows that a properly integrated parachute recovery system is an excellent operational choice and may result in overall weight and cost savings for the RPV. Other far-term, more advanced concepts such as stowed rotors, high lift technology and retrorocket system are too expensive, complex, or unreliable for near-term consideration.

SURVIVABILITY

The primary objective of survivability is to formulate concepts and to develop means for providing an RPV with an inherent low detectable signature. This approach degrades or denies target acquisition by enemy weapon systems that use the aircraft signature characteristics for surveillance or guidance. RPVs may be identified and acquired as targets by techniques ranging from unaided visual and audible detection to highly sophisticated optical and electronic sensing.

Countermeasures against threat systems can involve reduction of the RPV signature, or use of an efficient combination of both signature reduction (passive countermeasures) and deception (active countermeasures). Ideally, passive countermeasures are designed into the RPV at minimum penalty. Signature reduction, which is normally broadband, is effective against a variety of weapons. The subtechnical areas discussed under this subdiscipline are defined in table RV–A.

Significant low-penalty broadband reductions in radar cross section (RCS) can be made in the design of RPVs by shaping and carefully applying radar-absorbent materials. Shaping studies have shown that basic reductions in RCS are possible and analysis is required to define structural trade-offs such as shape, cost, etc.

The survivability contribution of RCS reduction against the current primary threat is being assessed. Hardware evaluation of this assessment is planned. Continuing analysis of existing and anticipated threat radar systems is required to determine the most effective approaches for countermeasures. A continuing emphasis, as technology changes, is required in the following areas:

- Improved definition of threat weapons characteristics to properly assess countermeasures capability.
- Improved analysis procedure to evaluate missile and RPV engagement and to determine the probable level of survivability.

TABLE RV–A
REDUCED DETECTABILITY SUBDISCIPLINE DESCRIPTION

ACOUSTIC	• **Pertains to definition of radar reflectivity (echo) of RPV systems. Selection of echo reduction in relation to threat system and deployment.**
VISUAL	• **Pertains to definition of IR emissions from engine and RPV systems. Application of reduction techniques and hardware design is based on threats analyzed for required countermeasures.**
INFRARED	• **Pertains to the investigation and definition of RPV features that provide significant visual detection cues. Concepts and techniques are developed and field evaluated.**
RADAR	• **Pertains to the definition and measurement of acoustic signatures, analysis of noise reduction, and survivability effects.**

Generally, visual countermeasures against an optical tracker or weapon aid are rather limited. Target characteristics that can be used for tracking are: contrast the background, point-to-point contrast across the target, and active lights on the target. A variety of paints have been developed to reduce visual contrast and to provide required IR reflection characteristics.

The worth of attaining reduced aural detection distance through reduced noise levels must ultimately be assessed by a survivability payoff. Noise provides warning of an approaching target, thus increasing the time available for readying optically sighted weapons. Where direct line of sight is not available to optical weapons, the noise signature usually provides warning. Recent studies of visual detection show a marked decrease in visual acquisition ranges when the aural cue is missing. The various areas of research pertaining to survivability through reduced detectability which are required are summarized below:

- Evaluate RPV development concepts for reducing radar cross section and determine the best potential configuration for future development of RPV vehicles.
- Conduct radar systems tracking angle error analysis for representative RPV radar cross sections for threat radar systems of interest.
- Conduct any required radar tracking field tests to verify RPV survivability requirements that cannot be determined by analysis.
- Design, fabricate, and test advanced concepts of low radar cross section to provide off-the-shelf technology for new mission systems.
- Apply available low reflectivity paints for evaluation during field testing to determine the best for future operational use.
- Apply available IR suppression technology to candidate RPV configurations to provide maximum IR radiation suppression.
- Design, test, and verify (when required) conceptual systems to minimize IR emissions from candidate RPV configurations.
- Define detectable criteria and conduct detailed analysis of operational conditions to determine recommended noise levels.
- Support development of propulsion systems for reduction of noise.

Vulnerability reduction, another feature of survivability, provides protection for RPVs against ballistic projectiles and antiaircraft missiles by airframe application of materials and design techniques derived through research investigations. Vulnerability reduction technology is intended to increase RPV airframe survivability by minimizing the consequences of damage caused by projectile hits. The mechanisms of kill included fire blast penetration and all the other means of failing and degrading the critical functional systems and components of aircraft, including structure, fuel, flight controls, propulsion, and mission equipment.

Areas of research required to develop technology – reduced RPV vulnerability to combat damage are summarized below:

- Investigate "soft" structural material concepts that will provide minimum structure damage from ballistic hits and maintain airframe structural requirements.
- Perform ballistic tests of candidate RPV structures designed to minimize ballistic damage.
- Identify the major vulnerability contributors of each RPV system and suggest design changes for improvement.

RPV CONFIGURATION OPTIMIZATION

The Army currently has extensive research, analytical and test efforts under way to determine if RPVs can supplement other air and ground means for obtaining intelligence information and directing firepower. The configuration of the RPV can greatly affect the cost effectiveness of the overall system. Depending on performance requirements (such as speed, maneuver, and endurance), a number of configuration approaches may prove to be optimum in terms of size, weight, fuel, and cost considerations. A parametric design study, covering a wide range of design and performance variables, will be used to identify promising vehicle configurations and establish a data bank to provide the base for the rational definition of RPV system requirements.

Many RPVs constructed in the past have been large, high-speed jet and rocket-propelled vehicles. The state of the art in small jets indicates a present lack of small jet engines, with little likelihood of obtaining the low fuel consumption values required.

Thus, small RPVs will rely on small reciprocating engines. Propulsion systems will use either propellers or ducted fans.

Sufficient aerodynamic data appear to be available for prediction of vehicle lift and drag characteristics, although correlation is necessary. Pitching moment effects at lower Reynolds numbers indicate problems occur at high lift coefficients. Sudden excursions into instability regions have always been indicated at low Reynolds numbers on wind-tunnel models. These pitching moment characteristics do not occur at higher Reynolds numbers. The judicious use of fences has been known to provide a solution to the problem. Wind tunnel tests of the full scale aircraft can lend to solutions of these problems.

Some progress has been made on correlating propeller performance on small propellers by properly adjusting the drag values for low Reynolds number effects. The smaller diameter propellers at their lower Reynolds numbers indicate lower overall efficiency as expected. A ducted Hamilton Standard Propeller method is available which has not been tried but may indicate an approach to use in obtaining performance of ducted propellers; however, this is a proprietary program.

The differences in characteristics of wings of low Reynolds numbers are sometimes opposite in effect to those known to improve wings at larger Reynolds numbers. Stability and control characteristics due to these differences cannot be predicted by conventional aircraft design methods. Wind-tunnel tests and free-flight tests would be highly desirable.

RPVs, because of their light weight, low wing loadings, and low inertia, are very susceptible to gust effects and wind variations. To maintain control and, particularly, heading, attention must be paid to static stability and low-speed characteristics. Tailless vehicles with medium aspect ratio wings have high gust sensitivity. Low aspect ratio delta-wing platforms, such as those used on high-speed, low-altitude aircraft, have low lift curve slopes and therefore are relatively insensitive to gusts; they may be particularly applicable to RPV designs. Thus it would appear that delta or low aspect ratio wing platforms yield the most favorable stability and control characteristics for RPVs.

Research is needed in the study of the variations of aerodynamic effects at the low speeds, small chords, and correspondingly low Reynolds numbers of RPV configurations. Sufficient data can be correlated to provide a good base for performance estimation. Propeller performance, in the small sizes required, must be studied, including fixed pitch, two pitch, and variable pitch designs. Compilation of engine data, including fuel consumption, is also necessary. Definition of the following parameters is needed: ranges of payload size and weight variation; power requirements; endurance and range variations; cruise, dash, and minimum speed variations including takeoff and recovery speeds; wing loading; planform and aspect ratio variations; and stability and control requirements. Parametric design study limits will be ascertained so that a matrix of design parameters and conduct parametric studies can be established.

The most practical small engines suitable for mini-RPVs seem to be two-cycle engines, but the whole area of small engines needs further investigation and systemization. Reliable performance data are available on only a few small engines. Presently a 20-hp engine is under contract and results from this program will contribute much to the state of the art; however more data are needed on small engines.

Thus far it has been discovered that present low speed requirements of the AQUILA design have a significant effect on engine and aircraft size of RPVs. These requirements force the aircraft in the direction of larger wing areas and larger power plants, thus compromising the size of the RPV. A better definition of requirements for low speed is necessary to determine whether those RPV compromises are necessary.

In summary, a wide range of vehicle configurations will be analyzed against a matrix of mission and performance requirements. Effects of various vehicle concepts, wing planforms, wing loadings, and propulsive concepts on vehicle size, weight, power, and fuel requirements will be defined and optimum designs identified for a range of mission requirements.

STRUCTURES

The RPV structural components program will provide a lightweight, low-cost RPV airframe suitable for mass production. The airframe will utilize advanced components technology and will draw on knowledge and experience accumulated from previous work in Army airmobile systems. Testing will be performed to

verify the applicability of the materials and techniques to RPVs. In FY77, the best material/technique combinations will be selected for future Army RPV production. This construction technique will be subjected to extensive tests. Applicability of composites to various fixed-wing RPVs other than AQUILA will be investigated, as will fabrication and testing of blades/propellers.

Several candidate construction materials and techniques offer significant possibilities of lightweight and low cost for RPV airframe construction. The lightest material appears to be a wet filament-wound foam sandwich. This material, which can be used for outer skin and for spars, can be mass-produced at low cost. Other candidates include thermo-plastic sheet for the outer skin in combination with various spar concepts. It appears that the outer skin could be either vacuum formed, rotationally molded, or blow molded. Several types of plastic sheet could possibly be used for the outer skin, depending on a trade-off analysis of strength, rigidity, weight, and cost. Another construction method is hand lay-up. However, this method is not suitable for mass production. Weight penalties and quality control problems are other hazards with hand lay-up.

LASERS

The laser program will develop a second generation laser designator/rangefinder for airborne applications. These equipments will utilize advanced laser technology and will offer advantages over current systems including modular design, commonality to other Army laser systems, lower weight, and higher brightness. The system resulting from this effort will be a tri-service coded, high duty cycle designator/rangefinder. Present 1.06-μ laser technology will shift to the 10-μ region in FY79. It will be the objective of this program to develop 10.6-μ laser technology and the interfaces required to provide FLIR integrated ranging and designation capabilities. Multifunctional systems such as these will yield significant savings in cost, maintenance, and reliability as well as in weight and overall performance.

RADAR

The main emphasis of the radar supporting technology program is to improve performance of components for the development of a brass board radar demonstration model; the model will weigh about 400 lb while the required RPV radar weight is 35 lb.

One element of this radar program will provide a lightweight, low-cost combination transmitter-receiver for the mini-RPV millimeter surveillance radar. The present transmitter-receiver module with its power supply and modulator accounts for a large part of the weight of the brass board radar. This element requires the development of such millimeter components as balanced mixers, circulators, and component transitions. Without these components, the transmitter-receiver cannot be integrated into a common module and hence the 35 lb radar cannot be achieved.

Systems analysis efforts will provide the background data necessary to ensure that the prototype millimeter radar and the 6.2 technical support efforts (transmitter-receiver, components, data processing, antenna development) will mate in reducing the radar weight to 35 lb. Initial efforts will include: investigation of data link requirements to be compatible with the ICNS being developed for the RPV, required waveforms, and transmitter-receiver characteristics.

Another element of effort is antenna development. The brass board millimeter radar being fabricated for the feasibility demonstration has a 20-in. antenna producing an 0.43° azimuth beamwidth. Inspection of the AQUILA indicated that a nose-mouth antenna would have to be smaller, thereby increasing the azimuth beamwidth and reducing the radar's azimuth resolution. The antenna development effort will emphasize new approaches to produce an antenna compatible with the AQUILA or any future vehicle. A prime prospect could be a combined electronic-scanned array with a limited mechanical scan. This could drastically reduce the gimbal size and weight. It is envisioned that the antenna will be a line source of some type. The antenna development effort will include the research and development of the antenna element, means of obtaining dual polarization, the necessary millimeter wavelength phase shifters, distribution networks, and beam-steering techniques.

The development of an on-board processor will provide the necessary data compression for mating to the existing RPV data link. These techniques will be employed to send the radar surveillance data to a ground-processing station where target information will be extracted. Data from the millimeter radar flight test will be available for use in determining many of its characteristics. This effort will result in a small, low cost, lightweight on-board data processor that can be used to obtain the desired end product, a 35-lb millimeter radar sensor.

Under the CSTA mission funded SOFTAR program, techniques are being investigated for detecting and recognizing fixed targets at long ranges from helicopter platforms. By use of ground processing analysis the ongoing SOFTAR efforts can be expanded to cover stationary target detection by means of RPV-borne millimeter radars. This requires additional target and clutter signature measurements at 95 GHz, analysis of signature data obtained at the higher frequency and higher depression angles, and some further algorithm and processor development.

COMMAND AND CONTROL

Command and control, as used here, refers to the uplink to the RPV from the ground control station and the downlink, comprised of video and telemetry information. Advanced command and control systems should provide the user with anti-jam and multiple control capabilities for mini-RPVs. To provide an interim capability in the shortest period of time, two parallel approaches are necessary. The near term data links Integrated Communication and Navigation System (ICNS) will provide a line-of-sight capability with anti-jam protection necessary to operate against the jamming threat out to ranges of 20 km. The ICNS is an advanced development program. Final packaging of the ICNS will be determined for the 6.4 models after completion of a size/weight vs cost trade-off analysis. The 6.2 and 6.3 ICNS efforts will produce feasibility models for flight demonstration of the anti-jam line-of-sight, multiple-control capability at G-band. The ICNS efforts will result in flight test demonstrations of the equipment on manned aircraft and on the AQUILA RPV. The thrust of the 6.2 funding is to retain/obtain capabilities that are anticipated for future requirements; for example, extended range operations, multiple control, and beyond line-of-sight (from the Ground Control Station) operations. Techniques for improving video image quality are also being investigated.

VISIONICS

Visionics is the use of electronics to enhance vision. The application of visionics to RPVs is primarily directed toward television and thermal imaging sensors, and is being managed by the Night Vision Laboratory.

Two new programs, which will adapt television equipments to RPVs, are a day/night solid-state imager program and a cost/weight reduction program for stabilized TV systems.

Devices based on charge transfer device technology, charge coupled devices or charge injection devices (CCD or CID), are envisioned as a television-type approach to low cost day/night imaging. As daylight charge transfer device technology grows, it should permit low-light-level operation as well as daylight capability from the same camera system. Based on general laboratory work in solid-state imagers and image intensification, an exploratory development day/night camera program was started in FY76. This program led to the design of a camera based on a focal plane density of about 200,000 elements and a demonstrator camera fabricated with a reduced number of imaging elements. The advanced design will be selected and integrated into an RPV stabilized platform and will subsequently be available for test and evaluation; as charge transfer devices are fabricated into larger arrays, the imager will be upgraded to provide higher resolution and better low light level performance. Stabilized television systems currently available for mini-RPVs should perform well but are too heavy and costly. Cost and weight reductions are driving factors, hence technology will be utilized in the construction, that is, plastic option, composite fiber structures, modular assembly for ease of fabrication, and interchangeable receivers for mission and cost flexibility.

Programs oriented to the adaptation of thermal imaging sensors to RPVs include a pyroelectric vidicon and a 3 to 5 μ thermal imager.

A pyroelectric vidicon detector is a low cost, and lower performance, approach to thermal imaging. Design goals are 2 km detection range and approaching 1 km recognition for a tank-size target. An exploratory development model, based on general laboratory technology, was initiated in FY76. This program will lead to a flyable brass board design in FY77 using a TGS or DTGFB vidicon target tube. The camera will be upgraded and further refined with a reticulated target tube and chopping with inversion processing added and may be integrated into a stabilized AQUILA RPV platform for evaluation.

A 3 to 5 μ thermoelectrically cooled thermal imager is based on an outgrowth of Night Vision Laboratory support in this technology on focal plane arrays, coolers, and rifle sight type systems. By FY78,

this technology should support exploratory development of a FLIR sensor with performance for some applications approaching that of cryogenically cooled systems.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in the Technology Introduction Section of the Plan. This section applies that process to the RPV technology discipline. The OPR is not an objective of the Plan, but is provided to show the procedure used by the Laboratory in the selection of programs within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The program objectives for FY78 are projected as follows:

- The 15-25 hp engine R&D program will provide the propulsion system requirements to meet the next generation of airframes envisioned for mini-RPV. The prime purpose of this program is to take existing two-cycle components and modify them, where necessary, to develop a multi-cylinder engine with a nominal 20 hp engine with growth capability to 25 hp.
- Engine testing efforts at MERADCOM will emphasize multi-fuel tests, lubrications tests, and noise testing. Efforts will be devoted to evaluation of engines from the 15-25 hp R&D program.
- Recovery efforts will center on the evaluation of the study contract initiated in FY76. Advanced recovery systems will be designed, built, and validation tested.
- The RPV configuration optimization studies on the fixed wing will be completed. The study will be expanded to cover rotary wing and VTOL RPV concepts.
- Noise reduction and visual detectability reductions for aircraft of the AQUILA configuration will be the major thrust of the survivability program.

PROGRAM PRIORITIES

General. Table RV–B presents, in a prioritized listing, the RPV technology subdisciplines, subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

TABLE RV–B
PRIORITIZED RPV OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Air Mobility	I	• Airframe	I	• Vehicle Performance	I
• Command & Control	II	• Command & Control	II	• Survivability	II
• Visionics	III	• Ground Control Station	III	• Controllability	III
• Lasers	IV	• Mission Payloads	IV	• Target Acquisition and Designation Capability	IV
• Radar	V	• Ground Support System	V	• Reliability	V

Technology Subdisciplines. The RPV technology subdisciplines are as discussed in this section and consist of the following major topical items:

- Air Mobility
- Lasers
- Radar
- Command and Control
- Visionics

Subsystems. Subsystems, as related to RPV technology, are categorized as follows:

- Airframe
- Command and Control
- Ground Control Station
- Mission Payloads
- Ground Support System

System Effectiveness. In the area of system effectiveness, performance is the primary element. Life-cycle costs are not ranked in the priority listing since the system must be a low cost item to be effective.

Priorities. With reference to table RV–B, the RPV subdisciplines, subsystems, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the RPV technology development R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the RPV supporting technology development program.

The RPV supporting technology thrusts are fivefold:

- Improve performance
- Increase survivability
- Improve controllability
- Develop target acquisition/designation capabilities
- Increase mini-RPV reliability

These thrusts are interactive and require expertise from several disciplines as shown in figure RV–2. Each of these thrusts are directed toward the development of a capability that does not now exist in mini-RPVs.

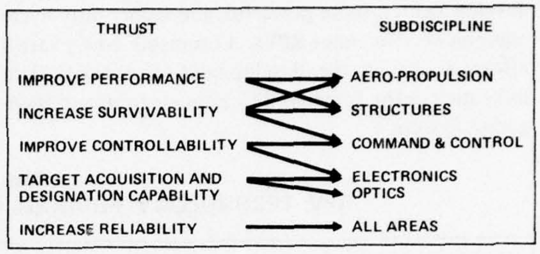


Figure RV–2. RPV program thrusts.

LABORATORY PROJECTS FOR FY78 IN RPV TECHNOLOGY

INTRODUCTION

RPV technology development effort is directed towards exploratory development (6.2) and was a new start in FY76. The program is particularly responsive to the requirements set forth by AVRADCOM's RPV Program Manager.

All developmental efforts are conducted by the Applied Technology Laboratory, Fort Eustis, Virginia, either by in-house efforts or by contract. Support is also obtained from MERADCOM, TECOM, HEL, NVL, CSTA, and Avionics Laboratory.

DESCRIPTION OF PROJECTS

Remotely Piloted Vehicle Technology. Project 1H262209AH76–TA IX has been phased out according to plan and all RPV 6.2 R&D work will be accomplished in Project AF34.

Remotely Piloted Vehicle Supporting Technology. Project 1L76273AF34 was established in FY77 to develop and evaluate new technologies in those factors which currently limit the operational potential of RPVs for Army missions. Emphasis will be given to the development of command and control equipment, lasers, radars, visionics, and air mobility capabilities. Day, night, and all-weather capabilities will be developed for mini-RPVs for several Army missions. These capabilities do not now exist within the services. Specifically, developments will be pursued in

propulsion, launch and recovery, survivability, and manufacturing technology for low cost, mass produced vehicles. Visionics developments include cost/weight reductions on day TV, thermal imagers, and low-light-level TV. Radar developments will emphasize all-weather capabilities; and laser programs will develop lighter, more powerful, and higher duty cycle equipments for mini-RPVs. Command and control efforts focus on the development of anti-jam data links such as the Integrated Communication and Navigation System.

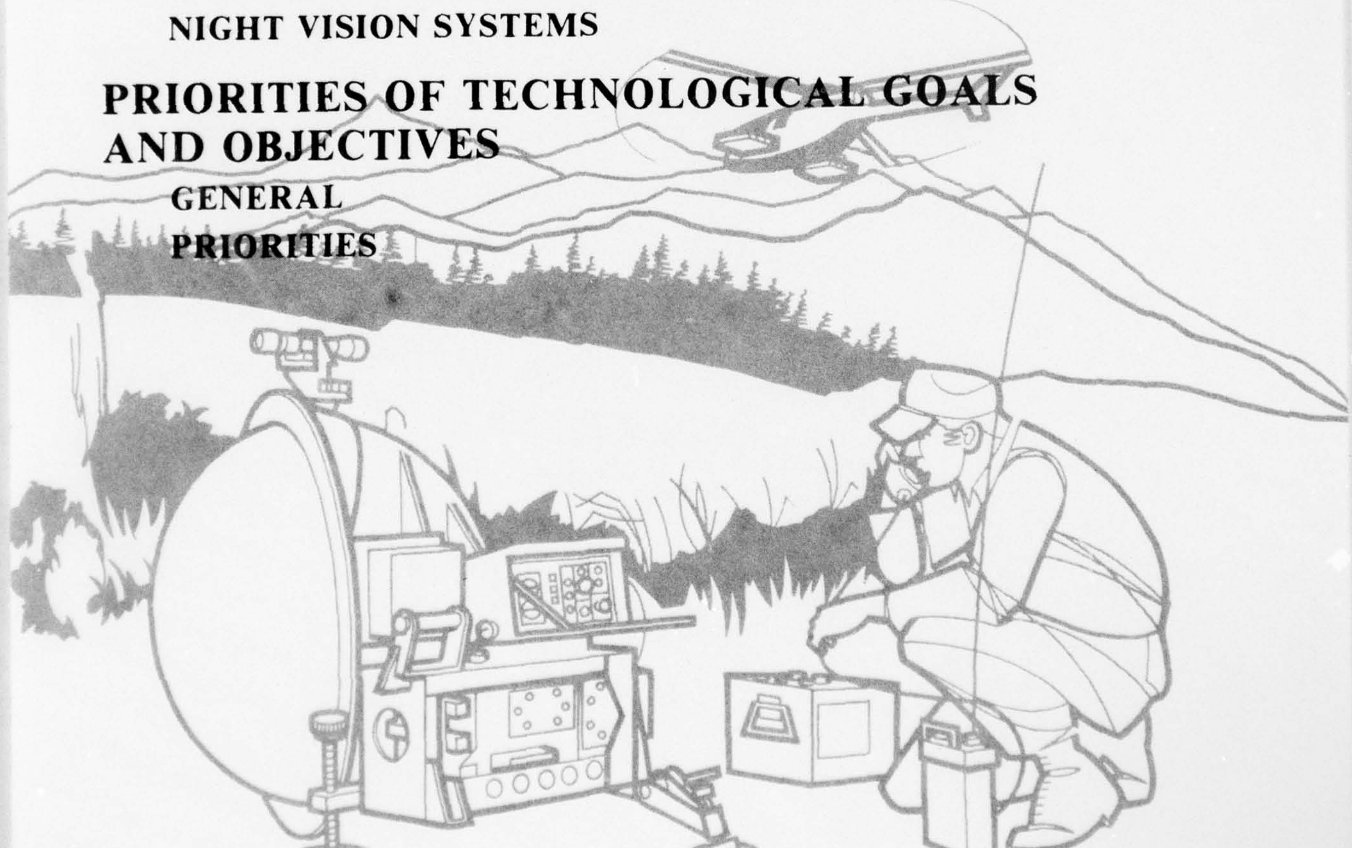
FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the RPV technology R&D efforts as presented in the technical discussion are shown and discussed in the Resources Required section. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 R&D efforts are shown in table RV–C. Included in the table is the ratio of the RPV technology efforts to the total 6.2 Laboratory R&D efforts.

TABLE RV–C
RPV TECHNOLOGY FUNDING (COMMAND SCHEDULE) FOR FY78

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 78	
6.2	1L262209AH76-TA IX	0	0%
6.2	1L762732AF34	1200	8%*

*Does not include Project 1L262201DH96 Aircraft Weapons Technology funds.



INTRODUCTION

Aviation electronics equipment is either airborne or ground equipment, used in support of aircraft, that relies primarily on electronic implementation. The US Army Electronics Command has the overall responsibility for avionics research and development within the Army. The US Army Aviation R&D Command, as Weapon Systems Manager, provides guidance and direction in close coordination with the ECOM Avionics Laboratory, the Research and Technology Laboratories, and AVRADCOM Project Managers. Avionics subsystem/system R&D efforts provide avionics/interface candidate information and equipments for the trade-off analyses and final system syntheses by the aircraft system designers. Army aircraft in support of ground tactical elements will depend on improved avionics to provide day/night and adverse weather capabilities for increased survivability and mission capability.

Major increases in the effectiveness of future Army aircraft systems, in a mid-intensity environment, greatly depend on increased avionic capabilities. This greater effectiveness will require more avionic functions, which will tend to increase the space, weight, and power provisions to accommodate these new functions. However, the continuing development of smaller and lighter electronic devices will offset these increases somewhat. Note that, although the required avionics functions may increase sharply, the overall increase in avionics weight will be comparatively small. These new functions generally reflect improved aircraft system capability from day to clear night to adverse weather, low-level operations.

Avionics are indispensable to the total aircraft system and represent a substantial part of the total cost of the system. In this respect, aircraft of a generic type having multiple mission roles are equipped with provisions for the various avionics systems, but the equipment is selectively installed according to the requirements of the particular mission. This concept must be evaluated for each particular aircraft with respect to maintenance and weight consideration. Also, since aircraft usually remain in the Army inventory for 20 years or more, second-generation avionic configurations become logical candidates for future retrofit programs for in-service aircraft.

The near-term avionics R&D objectives, the major thrusts they support, and the current projects to meet the objectives are shown in figure AV–1. Full use of airmobile systems is directly affected by technological advances in these avionic activities. Mission requirements such as those associated with night operations and weapon detection and location are examples of near-term R&D goals. Helicopters require avionics systems that integrate instrumentation and sensors to accomplish specific tasks. Typical fixed-wing avionics are no longer altogether acceptable for helicopters. Low-level night operations will require further delineation and corresponding development in obstacle detection and avoidance, pilot night-vision systems, precision hover, low-level navigation, non-line-of-sight communications, stability augmentation, integrated instrumentation/displays, and ECM (passive and active). The avionics package, along with the other major subsystems (airframe, propulsion, and weapons), must be adaptable to both single and multiple missions. Life-cycle costs and reliability, availability, and maintainability system trade-offs are essential parameters to the selection of final aircraft system designs.

The aviation electronics portion of the long-range plan has nine functional areas:

- Avionics Systems
- Communications
- Navigation
- Tactical Landing
- Air Traffic Management
- Environment Sensing
- Instrumentation
- Surveillance and Target Acquisition
- Night Vision

Each area is discussed individually, with specific emphasis on on-going and future programs.

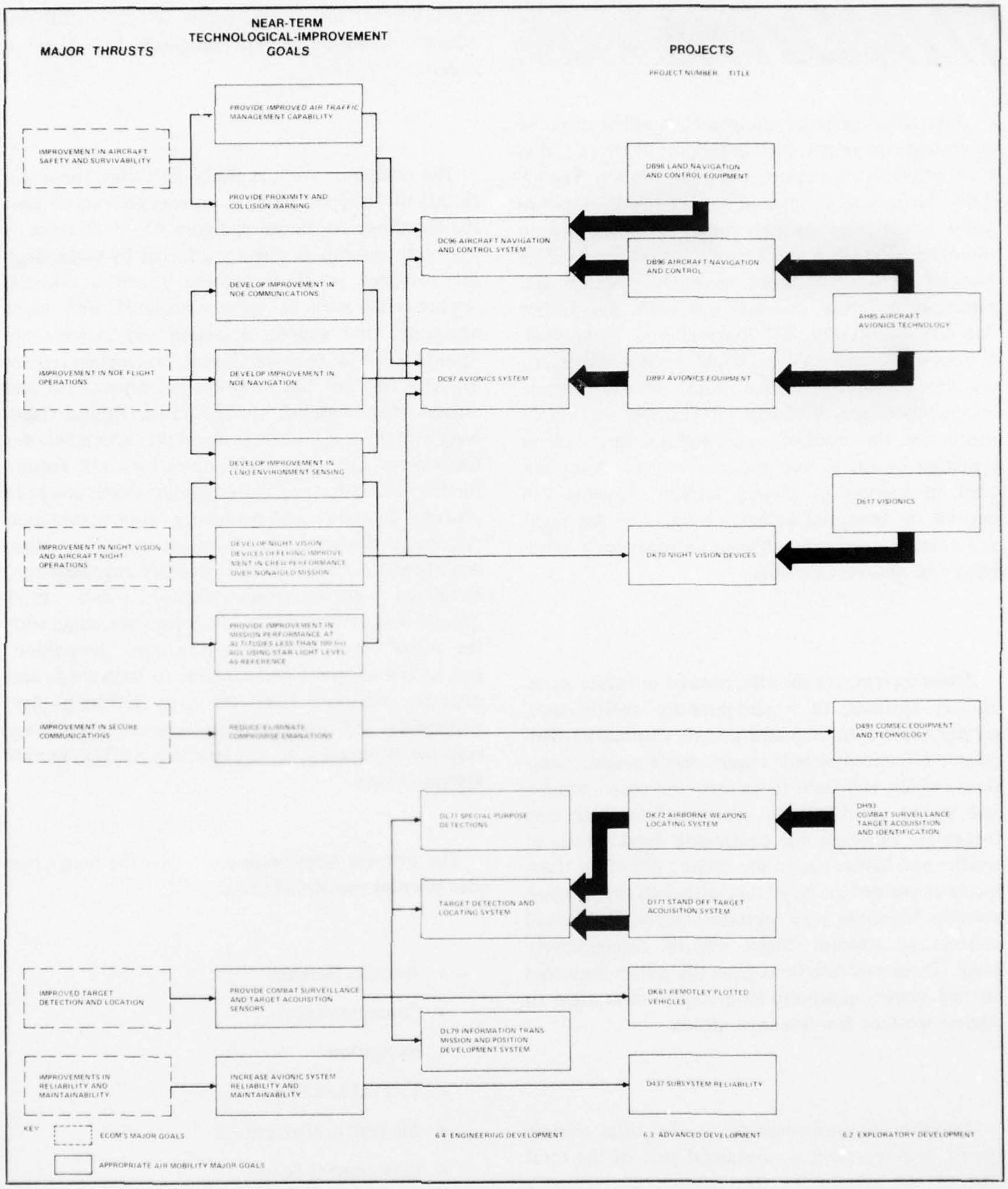


Figure AV–1. Research and development program flow diagram.

TECHNOLOGICAL DISCUSSION

AVIONICS SYSTEMS

GENERAL

An advanced avionics system is required to interface new avionics technology with the operational requirements of Army aircraft. The primary thrust of this program is an early flight-test validation and evaluation of various avionic equipment sets – the "fly before require" concept. This pragmatic approach to systems engineering is comprised of an iterative, three-step process of analysis, simulation, and flight test. The results thus obtained form the basis for avionics system-level specifications for developing and improving Army aircraft. Another use of this technique is to identify required advances in specific technology (e.g., navigation and environment sensing) that should be investigated further. To accomplish the above, the following efforts and capabilities are mandatory:

Analysis. The initial effort involves the translation of specific mission requirements into candidate avionics hardware configurations, with special emphasis on identification of the subsystem characteristics (accuracy, range, power, etc.) and system characteristics (EW vulnerability, EMI compatibility, and equipment interfaces) necessary for a specific mission. These efforts also serve to identify those problems that cannot be solved analytically – problems that require simulation and flight test. After candidate hardware configurations have been proposed, the application of advanced system integration techniques (digital/modular integration, light interface technology, data bus, multiplex, etc.) is considered for each hardware integration program. The most restrictive barrier to the success of this effort is the acquisition of a well-coordinated, generally accepted description of the mission to be accomplished, without prejudgment as to what equipment is necessary to execute the mission. This barrier must be addressed through close, continuing coordination between the using and developing communities.

Simulation. The objective of this effort is to develop hardware integration concepts for avionics configurations that have been identified under the analysis effort as candidates for further development, and to forward the most promising concepts to flight test for validation of the hardware integration plan. This objective is achieved by utilizing the simulation facility as an evaluation tool in a five-step approach:

- The simulation test activity is used for a relative evaluation of avionic system configurations developed under the analysis effort.
- For those configurations with satisfactory simulation results, a bench test facility in the simulator is used to demonstrate the feasibility of the hardware integration technique.
- Computational requirements are identified for integration of the candidate configurations.
- The simulation facility is used as a preflight training aid in the preparation and evaluation of a flight-test plan.
- The facility is used as an avionic system design tool for those cases that cannot be handled by the analytic approach previously described.

There are two major barriers in the simulation area. The first barrier is the digital computer execution time of a complete model of a single rotor helicopter consisting of the six aircraft fuselage degrees of freedom, the rotor rotational degree of freedom for autorotation, and algebraic expressions for the rotor first modal coning and flapping. As this model usually requires 30 milliseconds to execute (out of a permissible 50 milliseconds), very little computation time remains to simulate avionic-related functions. This barrier is being attacked by the development of a special purpose analog helicopter simulator. The second barrier is the difficulty in correlating the information content of a video display for the pilot (presently accomplished with a TV/moving belt system) with the information content from simulated sensors such as a CO_2 terrain-scanning laser. This is being addressed by acquisition of a digital land-mass simulator which will have the potential for generating the video information and the avionic sensor information from a common data base.

Flight Test. The objective of this effort is to provide an airborne test activity for validation of avionics hardware configurations. This objective is achieved in four ways:

- An instrumented test bed aircraft (CH-53A) is used to prove the performance capability of avionics systems and to validate the hardware integration concepts identified by analysis and simulation.

- The instrumented aircraft is used as an avionic systems design tool for those problems that were not amenable to analysis or simulation.
- The system designs and hardware that have successfully completed the above process are integrated in a representative Army aircraft to provide test data and dialogue between using and developing elements concerning the efficiency of proposed operational hardware and system configurations.
- All data and experiences gained in the analytic, simulation, and flight test phases of the test program are utilized to produce system level specifications for the avionic configurations.

There are two barriers associated with this flight test activity. The first problem area is somewhat philosophical, because it concerns the general acceptance of test-bed flight test results. It is considered reasonable that a simulation/flight test activity focusing on avionics can provide a valid data base for avionics equipment development without the human factors, aircraft stability and control, aeromedical, and other considerations having been optimized. The requirement in these associated disciplines is that their influence be reasonably considered. To insure the reasonable treatment of these influences on avionics equipment development requires close coordination and cooperation between the appropriate agencies. The second problem relates to the flexibility required in a test-bed type of a flight program – a flexibility that is somewhat difficult to achieve. It is mandatory from cost considerations that the ability to rapidly reconfigure the test aircraft be developed. This permits execution of overlapping or even simultaneous flight test programs and allows for a quick-reaction systems test capability.

In accordance with STOG-78 objectives of survivability and night operation, this three-step methodology is being applied to the synthesis of avionics systems suitable for tactical Army operation in the low-level (for survivability) night environment.

NIGHT NAVIGATION PILOTAGE SYSTEM

It is assumed that in this limited visibility environment, the pilot will rely heavily on imagery generated by sensors, such as the forward looking infrared radar (FLIR), to perform his mission. Under such circumstances, the limited field of view and the decrease or lack of depth perception would deprive the pilot of some of the important visual cues normally available to him under visual conditions. The approach taken to alleviate this condition is to present the pilot with symbology that provides command and/or situation information to supplement his visual imagery.

Pilotage Display. The digitally generated symbology is superimposed on background video scenery (figure AV–2) and is driven by signals derived from on-board aircraft sensors. One of the important design constraints in this program is to maximize the use of available on-board sensors so that special purpose hardware can be kept to an absolute minimum.

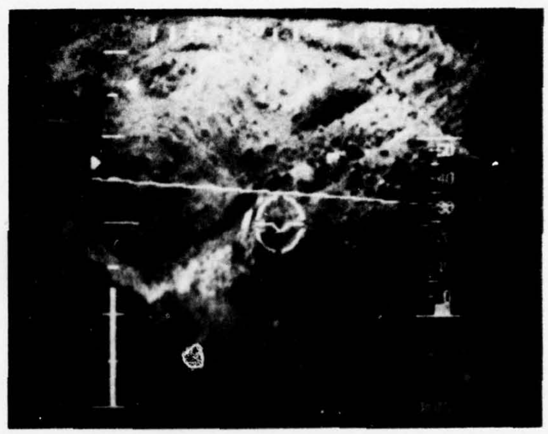
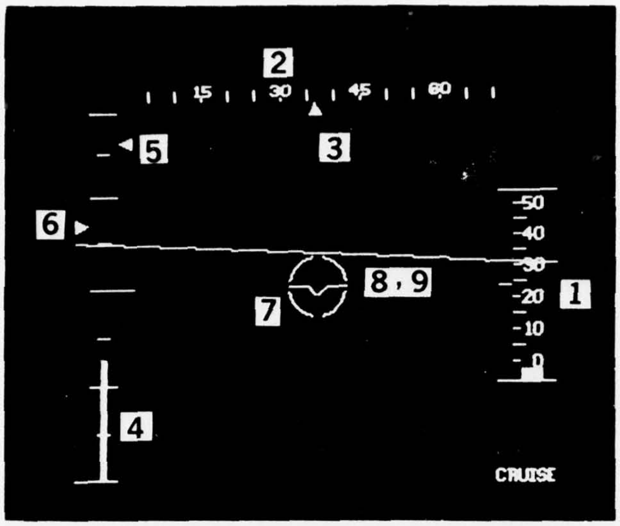


Figure AV–2. Background video imagery with symbology superimposed.

The symbology program designed for night pilotage operations is configured in four modes according to the phase of the Army flight mission being conducted. Symbolic information common to all four modes is presented on the periphery of the display. Symbols peculiar to each mode are presented in the central portion of the display. The four selectable modes are:

- Cruise – high speed enroute level flight (see figure AV–3)
- Transition – lowspeed NOE (nap-of-the-earth) maneuvers (see figure AV–4)
- Hover (see figure AV–5)
- Bob-Up (see figure AV–6)

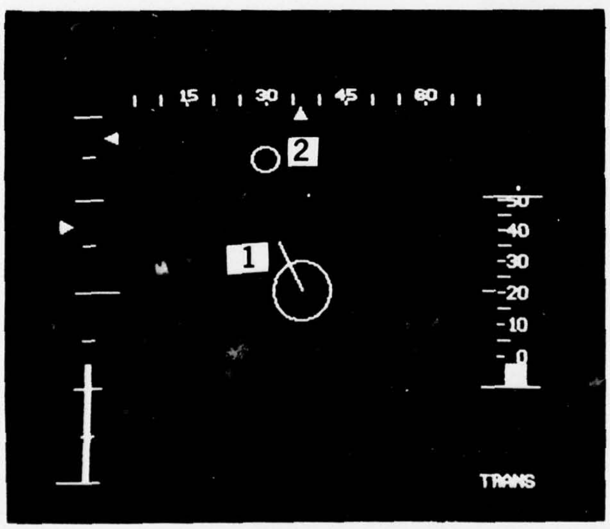


SYMBOL DEFINITION

1. INDICATED AIRSPEED
2. AIRCRAFT HEADING
3. HEADING COMMAND
4. RADAR ALTITUDE
5. RATE OF CLIMB
6. ENGINE TORQUE
7. AIRCRAFT NOSE REFERENCE (FOR USE WITH A HELMET MOUNTED DISPLAY, HEAD TRACKER, TURRETED FLIR SYSTEM)

8., 9. ARTIFICIAL HORIZON AND REFERENCE

Figure AV–3. Cruise display.

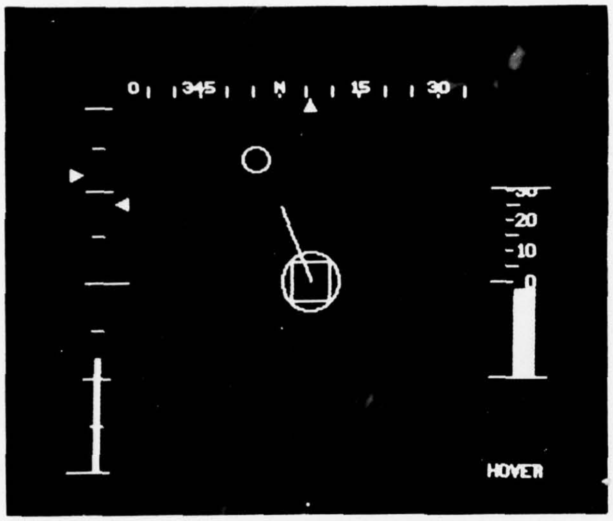


SYMBOL DEFINITION

1. AIRCRAFT GROUND VELOCITY
2. AIRCRAFT HORIZONTAL ACCELERATION (REFERENCED TO VELOCITY VECTOR TIP)

Figure AV–4. Transition display.

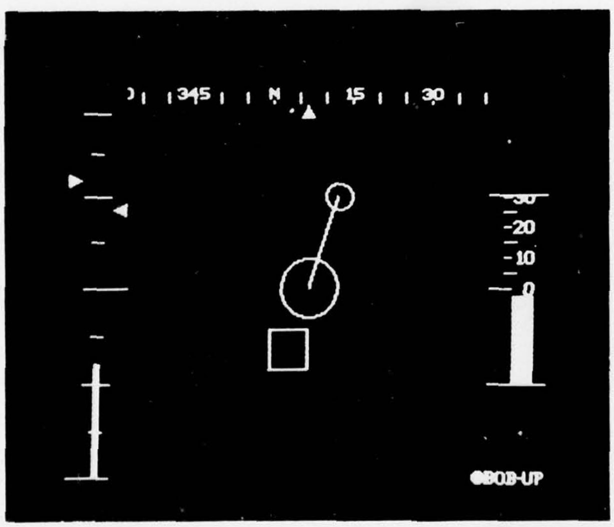
Navigation Display. One of the main requirements for the successful execution of an NOE mission is the ability to navigate accurately by means of visual pilotage. For the daytime NOE mission, the basic element of this ability is map interpretation. Visual pilotage is a process of correlating features in the visual presentation (the windscreen) with those portrayed on a map. This is the process of map interpretation, not mere "map reading." Experienced NOE pilots have refined this skill to a high level of proficiency, and their perception of terrain is acute. Key information to an experienced NOE navigator is in terms of drainage



SYMBOL DEFINITION

THE FIXED SQUARE SYMBOL DENOTES THE NORMAL HOVER REFERENCE POSITION AND IS ACTIVATED IN THE BOB-UP MODE

Figure AV–5. Hover display.



SYMBOL DEFINITION

THE TRIANGULAR POINTER IS USED TO DEPICT INSTANTANEOUS DEVIATION IN HEADING DURING THE BOB-UP MANEUVER

Figure AV–6. Bob-up display.

patterns, contour shapes and elevation gradients. Man-made features are of lesser importance in tactical situations.

The navigational task is even more challenging to the pilot-navigator at night. All state-of-the-art night vision systems represent a loss in visual acuity over the daytime "out-the-window" capability. Instantaneous fields-of-view limits are at least 50% of the daytime range. Map reading or operating and updating navigation equipment in a semilighted cockpit are burdensome to the copilot. Aside from addressing

these night operational problems, possible improvement to the present configuration of the navigational task should also be examined.

Enroute navigation during the nap-of-the-earth (NOE) flight is currently performed by the copilot. This is necessitated by the fact that the pilot cannot simultaneously look down at his maps and retain his forward-looking view. As a result, navigation information is transmitted through the verbal and audio channels of the pilot and copilot. There are several disadvantages associated with this present configuration.

- A copilot is always needed to perform the navigation task.
- The audio navigation inputs to the pilot may not be the most direct and precise in terms of their nature and information content for the initiation of control stick actions.
- The intra-communications among the pilots may impede other necessary communications with the outside.

The purpose of this effort is to develop a versatile display that combines navigation as well as flight information. This display could be used as desired by both pilot and copilot. The underlying assumption for this approach was that by making navigational information directly available to the pilot, the necessity for the pilot and copilot intra-communications is minimized. The navigator becomes more free to update the map accurately, to communicate with the outside, and to monitor potential flight path intrusions from neighboring aircraft. The pilot, on the other hand, has a direct preview of the forward terrain with which to conduct more effective pilotage. With automatic updating, the pilot also has a potential for completing the flight mission single-handedly in an emergency situation.

As in the case of flight symbology, the CRT has been found to be an excellent means of providing NOE navigation information. The flexibility provided by the CRT permits a navigation map to be superimposed with flight symbology as shown in figure AV–7. This composite picture can be provided on a panel mounted display (PMD), a helmet-mounted display (HMD), or on specially modified night vision goggles. The navigation display is decentered. The aircraft's present position is indicated by the arrow at the bottom of the screen. This leads to a considerable amount of rotational map movement for rotary winged vehicles. Thus, planned course up and

Figure AV–7. Navigation map with flight symbology.

filtered heading up modes are also being examined. In simulation test results to date, subject pilots were able to complete all flight routes, using the automatically updated electronic map. Further simulation experiments on digitally generated electronic maps are planned together with efforts associated with the hardware and software necessary for their generation.

Near-term objectives for the Night Navigation Pilotage System program include engineering flight test of the system concept in the instrumented test bed aircraft. This will be followed by integration of the system in a representative Army aircraft (UH-1H).

DIGITAL MODULAR SYSTEM INTEGRATION

In order to exploit this new technology area, two efforts have been undertaken. The first is an engineering development effort called the Integrated Avionics Control System (IACS). The program goal is to apply currently available technology to a system integration scheme which will provide the Army with a digital modular avionic system in the near-time frame (early 1980s).

The second effort is a long-range exploratory development effort called the Digital Modular Avionics Program (DIMAP). This exploratory effort provided the technology base for the IACS program and will provide the technology base for future efforts in digital modular system integration.

The field problems being addressed in both cases are the proliferation of avionic equipments in the helicopter cockpit (this was and is reaching the point

where in certain aircraft space is not available for some of the basic avionics); the desire for more capability (such as pre-sets for radios and some cockpit management through the application of new technology); the desire for some control/display standardization to reduce training time for new pilots and familiarization time for experienced pilots flying various helicopters; the desire for a field reconfiguration capability (such as removal of CONUS equipments for tactical equipments) without drastic rework of the cockpit; the desire for ease of avionic retrofit during product improvement programs; and the desire that these field problems be solved by an evolutionary systems approach that does not obsolete the entire existing inventory. Complicating the situation is the fact that the Army deals with relatively small, inexpensive aircraft, dictating heavy emphasis on avionics systems that are small, lightweight, and low in cost – requirements that are conflicting with each other.

Historically, most of the "system integration" in the Army helicopter cockpit has been performed by the crew. Data from each subsystem is manually transferred or interfaced with other subsystems. Figure AV–8 is a representation of a typical Army helicopter avionics system. Note that each subsystem has its own dedicated display and control and, in some cases, computer. This approach to integration was the only feasible method a decade or more ago when these systems were designed.

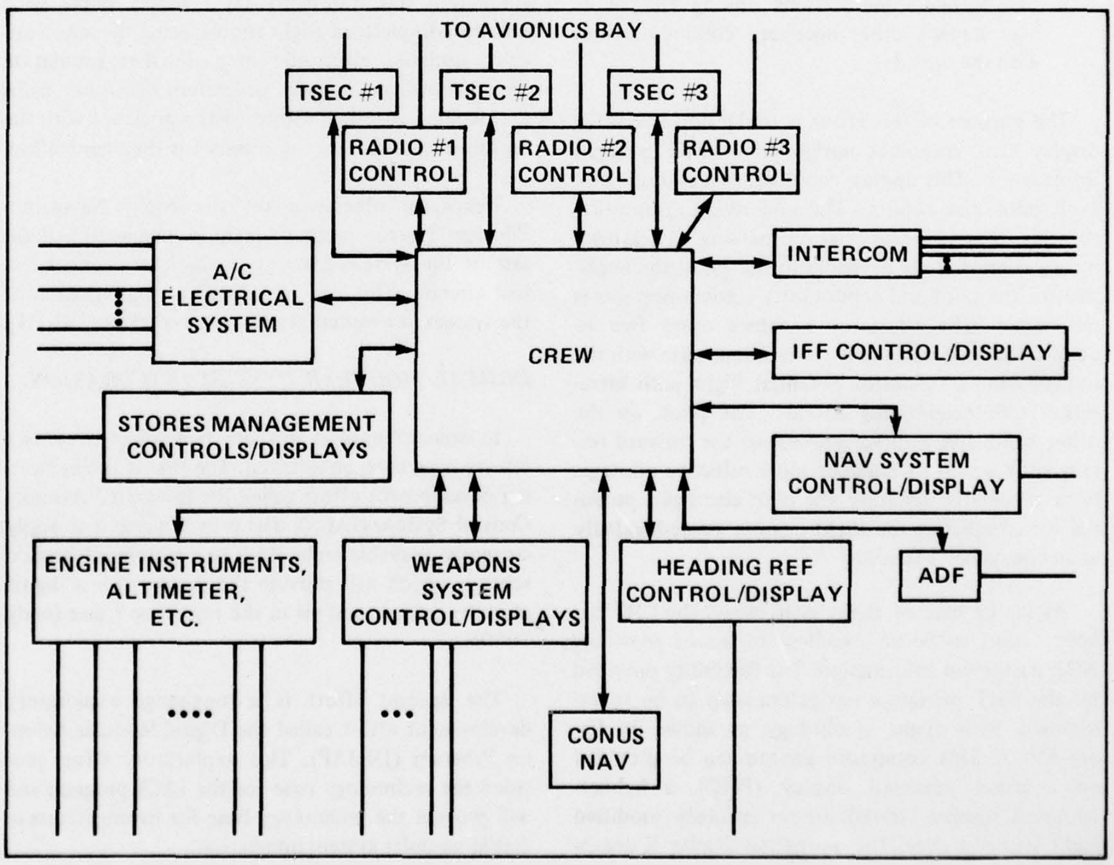


Figure AV–8. Typical Army helicopter avionics system.

The recent rapid advances in digital technology offers the avionic system designer an array of new tools which, if used properly, will reduce the interface between the crew and control/display equipments. Figure AV–9 is a representative block diagram of a digitally integrated helicopter avionics system.

This type of architecture is characterized by the use of a digital data bus to interconnect sensors, controls, and displays. This approach has the rather obvious advantage of integrating the information transmission medium. Thus, the bulky, complex wiring harness may be replaced by a twisted wire pair. There are, in addition, more subtle advantages which can have more far-reaching payoffs. These include the fact that the data bus architecture encourages (indeed, almost forces) the adoption of standard signal interfaces between pieces of hardware. Most significantly, the adoption of a system strategy that leads to this type of system integration provides a basis to address each of the field problems listed previously.

Another feature of this system is the use of small digital processors in the integrated displays, the remote terminals of the multiplexed data bus, and in the subsystems connected to these terminals. A larger general purpose machine can also be used to provide certain functions such as data bus control, digital map generation, symbol generation, etc. The ability to configure an avionic system in this manner (i.e., with a digital data bus) will lead to the development of black boxes with standard digital interfaces that can

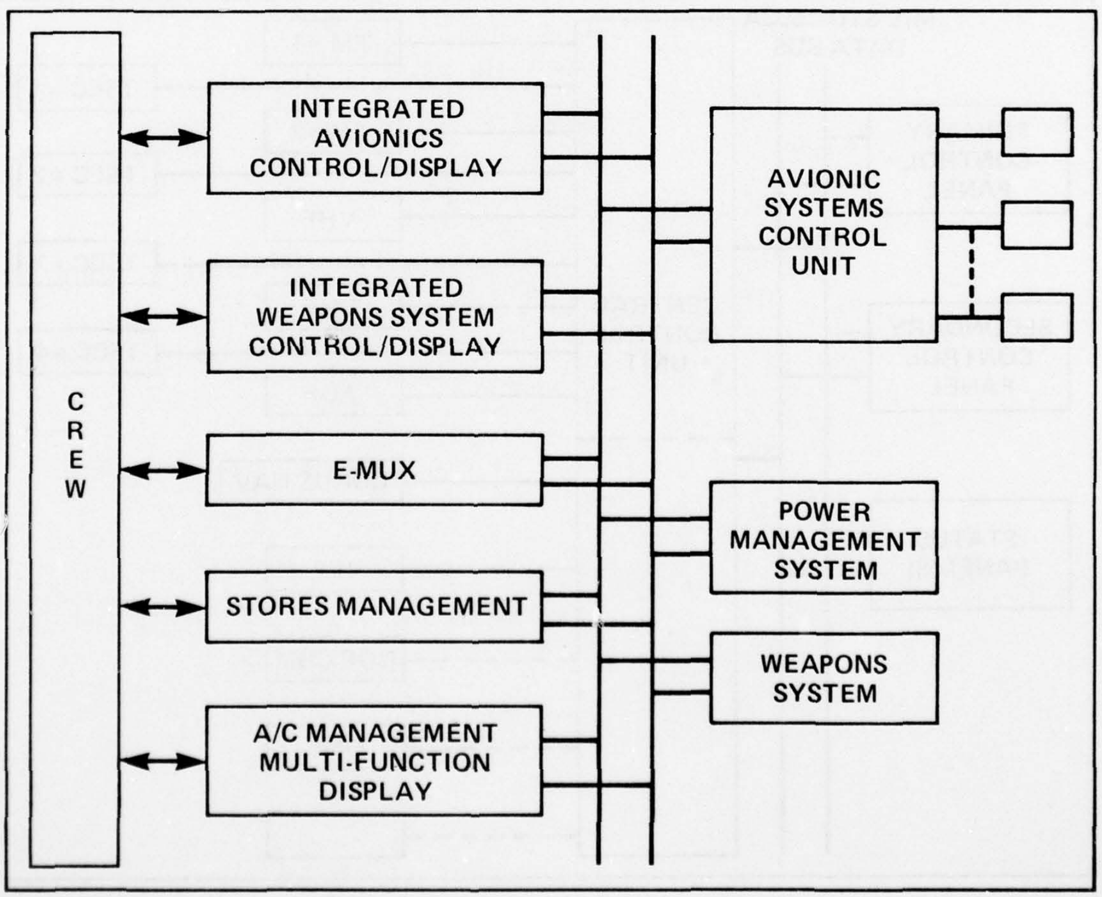


Figure AV–9. Digitally integrated helicopter avionics system.

be used by the three services. The ability to standardize hardware and interface, and provide a more efficient cockpit is the greatest long-term advantage inherent in this digital approach to cockpit and avionic system design.

The greatest problem facing a systems engineer, however, is how to make the transition to this more efficient cockpit. The revolutionary approach is not practical because of the logistics involved in replacing all current equipments with equipments that are capable of interfacing directly to the data bus, and at the same time introducing integrated control/displays for all aircraft functional areas into the inventory. This revolutionary approach is costly and introduces a level of risk that is unacceptable. Hence an evolutionary or building block strategy was adopted.

In brief, the strategy consists of integrating discrete functional subsets of aircraft equipments via integrated control display and a 1553A data bus, using existing standard subsystems wherever possible (e.g., IACS), specifying next generation equipments in each functional subset to be capable of directly interfacing with the data bus; and finally tying the diverse functional subsystems together through the data bus into a fully integrated system.

Integrated Avionics Control System. Under the Integrated Avionics Control System (IACS) program an integrated control/display panel will be developed which will control the mode and frequency of operation of up to 10 radios and their associated communication security equipments (see figure AV–10). This

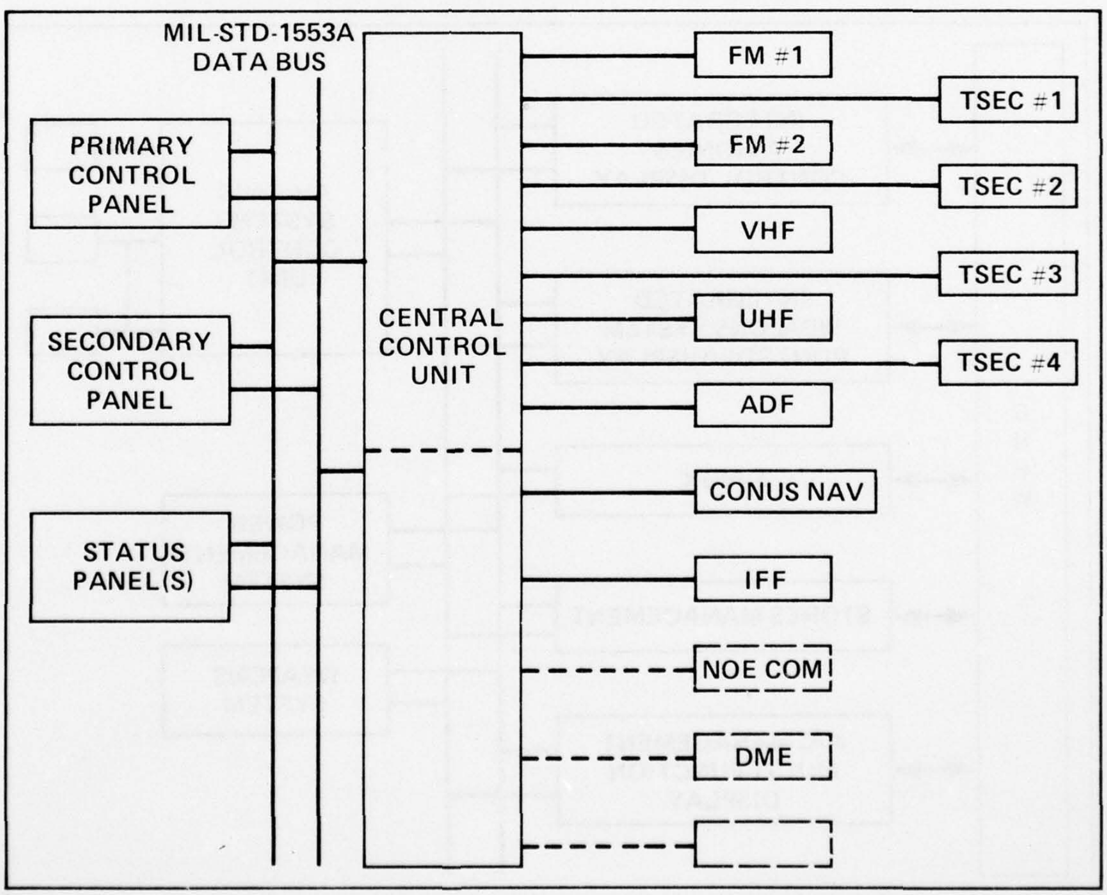


Figure AV–10. Integrated avionics control system.

one control panel can replace about 14 separate control panels that would be in the cockpit under the conventional approach to cockpit design. Also, additional capability can be added by providing preset frequencies for all the communication and navigation radios. In addition to this control panel, which can control all of the radios (referred to as the primary control panel), IACS includes a so-called secondary control panel and a status panel. The secondary control panel will have a lesser capability than the primary control panel. As a minimum, it will control the FM and UHF radios and the ADF. This secondary panel will be used in those cockpits for which space does not permit a primary panel for each operator. The status panel is an optional panel that will provide mode and frequency information in a separate display that can be mounted toward the top of the instrument panel to furnish the operator with nearly head-up type display. The primary and secondary control panels will be mounted either in the center console for a side-by-side helicopter or the side pockets for a helicopter with a tandem seating arrangement. All interface between the control panels, the status panel, and the central control unit or units will be via dual MIL-STD-1553A data busses. That is, all electrical interfaces in the cockpit and between the cockpit and the avionics bay will be via the data busses. For the initial deployment of this system in the 1980 to 1985 time frame, all subsystem equipments will be controlled through the central control unit. However, beyond that time frame, new subsystem equipments will be designed to interface directly onto the data bus.

Digital Modular Avionics Program. The Digital Modular Avionics Program (DIMAP) is the supporting technology base effort in the area of digital modular system integration. This technology base program is closely tied to the Air Force and Navy efforts in this area, especially in digital data bus techniques. A major goal of the DIMAP program is the establishment of a system integration facility (bench and flight) such that different system configurations can be synthesized and assessed prior to commitment to full scale development. Included in this effort will be a major reconfiguration of the Tactical Avionic System Simulator (TASS) to a fully integrated facility operating on a MIL-STD-1553A bus. The basic approach is to be able to configure a system on the bench, evaluate it, move into flight test and then spin off all or a portion of the system into full scale development.

MULTIFUNCTION USE OF SENSORS

The long-range avionics systems program must emphasize the use of sensors in multifunction roles in order to reduce the cost and weight of the overall system. One such effort is the Target Location/Navigation System Integration Program. One method for determining the UTM coordinates of an unknown target is to use a laser range finder to measure range and angles to the target, combine this data with the UTM coordinates of the aircraft (supplied by the navigation system) and compute the target coordinates. If the coordinates of the target being ranged on are previously known, the same procedure can be followed to compute the UTM coordinates of the aircraft and, thus, "update" the aircraft navigation system. Data on the accuracy with which this can be accomplished will be gathered. Potentially, at least, a self-contained navigation system could be "calibrated" by ranging on a known checkpoint when nearing the operational area of interest. The navigation system could then provide much better accuracy than would otherwise be possible. Initial tests are scheduled for completion in FY77.

Another example of multifunction sensor uses is the multifunction CO_2 laser. The Laser Obstacle/Terrain Avoidance Warning System (LOTAWS), a scanning CO_2 laser, has demonstrated the capability to detect wires and to function as a terrain sensor. The system has also demonstrated a hover augmentation capability, and the exploratory development effort is investigating the potential of this CO_2 system to perform the additional functions of range-finding and target designation.

AVIONICS SYSTEM ASSESSMENT

Realistic assessment of the relative merit of different avionics systems is a continuing and difficult problem. The interrelated areas of pilot workload, pilot opinion, and task performance precision all play a part, especially when aviation displays are being evaluated. When attempting to discriminate among several comparable displays, one typically finds the task performance precision data to be inconclusive "flat data." With the poorer system(s), the pilot simply works harder to achieve the same tracking error performance. Reliable techniques for accurate, repeatable assessment of the pilot's workload are therefore needed to provide the necessary discrimination. Such techniques are not presently available for

use in flight test. A promising technique suitable for use in ground-based simulation tests is being developed. Basically, it involves keeping the pilot working at his maximum capacity through manipulation of a single parameter, with the differing value of the parameter in tests of different systems serving as the discriminator. In order to address the flight test problem, attempts are being made to correlate variation in the physiological state of the pilot (heart beat, etc.) which can be measured in flight, with variations in this parameter during simulator experiments. Preliminary results are encouraging. More definitive flight tests are planned in late FY77 and early FY78.

EW VULNERABILITY/ECCM ASSESSMENT

Hostile electronic warfare activities present a serious threat to our ability to conduct military operations. Unless the seriousness of this threat is acknowledged and countered, it can degrade the ability of the military to shoot, move, and communicate, hence field weapons systems would not be effective against a sophisticated enemy. In recognition of the seriousness of this problem, the U.S. Army Materiel Development and Readiness Command issued the EW policy letter of 2 January 1974 that requires electronic counter-countermeasures to be considered in every DARCOM weapons systems development. As part of the implementation of this policy, EW vulnerability assessments were completed.

COMMUNICATIONS

GENERAL

Future Army aviation roles and missions impose new demands on Army airborne communication system performance. Communications performance and reliability is constrained by the masking effects of nap-of-the-earth (NOE) tactics which must be employed to survive in the enemy air defense environment, the anticipated electronic warfare threat, and the physical and flight safety problems associated with NOE, night/adverse weather conditions in the high ambient noise helicopter cockpit environment. These challenges require the introduction of new procedures, devices, and techniques.

These critical needs and affordability constraints require the exploration of various communication system/subsystem techniques to increase the utilization (i.e., multifunction use) of existing systems, the synergistic combination of required functions, and the elimination or minimization of known communication system deficiencies (i.e., audio intelligibility, aviator hearing loss, ECM, inefficient antennas, etc.).

The airborne communications programs are directed to improve the mission effectiveness of Army aircraft. The mission effectiveness depends to a large extent on the reliable interchange of information between and among Army air and ground elements (HF & FM), and between Army and supporting Navy, Marine, and Air Force aircraft (VHF/UHF-AM). To accomplish these objectives, the airborne communications R&D program addresses the following major thrust areas:

- Tactical Low-Level (TLL) and Nap-of-the-Earth (NOE)
- Audio Processing, Distribution and Isolation
- Multifunction/Integrated Use of Equipment
- Electronic Counter Counter-Measures (ECCM)
- Antennas

TLL and NOE communications encompass the requirement for reliable secure communications (i.e., air-to-air, air-to-ground, and ground-to-air), while aircraft are flying low level and NOE mission profiles.

The audio program efforts are related to NOE Communications; however, they are specifically directed to improve the quality and intelligibility of the aircraft audio system in order to eliminate health (aviator hearing loss) and safety hazards in the communications system.

The multifunction/integrated use of equipment efforts address the utilization of on-board radios for additional functions (i.e., homing, hover, bearing) other than communications, and the integration of such functions as communication control, display, and data handling within an integrated aircraft system design architecture.

The ECCM program is directed to obtain reliable tactical communications in an electronic warfare environment. This effort will be conducted in a sequential fashion (define operational procedures, develop appliques, and introduce new techniques) to meet current and future anticipated threats to the communication system.

The antenna program is in support of aircraft operations in the NOE and ECCM tactical environment. The program efforts are concentrated to improve communication system efficiency, decrease the number of radiating elements required by aircraft radios and use of steerable null processors to reduce the ECCM threat.

TACTICAL LOW-LEVEL COMMUNICATIONS

At the present time our nap-of-the-earth (NOE) communication system program efforts are directed toward meeting the near- and far-term communication requirements (air-to-air, air-to-ground, and ground-to-air) of Army aircraft flying NOE profiles. AN LOA (TRADOC/AMC)USATRADOC ACN 22213, dated 22 Jan 1976, has been approved. This LOA outlines a comprehensive test and analysis program to determine the capabilities, limitations, and effectiveness of improved VHF/FM, HF/SSB, and retransmission, to meet the Army's NOE Communication requirements. A major data gathering field test program (under varying environmental, terrain, and time-of-day conditions) has been completed by TCATA, at Fort Hood. The NOE Communication data base, consisting of the TCATA test results and numerous other data/analyses, are being evaluated by a TRADOC sponsored SAG and COEA special study group. The results will be presented at a special IPR in July 1977, at which time an NOE Communication System may be selected for development and/or procurement to meet near-term requirements.

The follow-on tactical low level communications development will consider the following alternatives to provide improved capability:

- The development of a cost effective HF/SSB aircraft radio system with a squelch, presets, and variable power output capability to provide NOE communications.
- The development of a VHF/FM applique (power amplifier, efficient antenna coupler, and antenna), to improve the aircrafts' tactical communications capability.
- The development of a communication systems applique (simplified data message entry device, selective calling, and frequency scanning pushbutton operation) to further enhance the aircrafts' NOE communications capability.
- The development of a multiband communications radio that would provide a size, weight, and cost savings without loss of functional capability. This equipment would be integrated into the DIMAP system.

Long-term approaches to provide Tactical Low Level (TTL) multiple channel, reliable, and secure communications, anywhere on the battlefield, include:

- Small RF repeaters, which can be installed in any applicable vehicle/ground station (e.g., aircraft, satellite, balloon, RPV, tower, etc.) and may also be used as standard transceiver.
- Time Division Multiple Access (TDMA) or Integrated Communication, Navigation, Identification (ICNI) systems (e.g., PLRS, Packet Radio JTIDS, GPS) which are being investigated by USAF, USN, and Army, for ground and airborne use.
- Advanced communication and antenna techniques utilizing signal-to-noise enhancement techniques to permit reliable communications in an EW environment.

AUDIO PROCESSING, DISTRIBUTION, AND ISOLATION

The audio program is designed to improve mission effectiveness and to reduce operating costs by improving the communications system audio quality and intelligibility, and eliminating the aviator hearing damage risk potential.

A series of tests has been initiated to obtain baseline data on the aircraft communication systems in operation in the Army. The information derived will be used to establish new standards and specifications, to develop inspection procedures, and to develop appliques to improve system performance and reduce excessive noise levels noted.

A MACI program is presently in progress to develop a flat-response noise-cancelling microphone for incorporation into the aviator's helmet. This microphone will exhibit an improved frequency response to improve speech intelligibility and to reduce the sound pressure level at the aviator's ear. Improved microphones have been obtained and are being tested prior to selection of a candidate replacement for the current M-87/AIC.

A design program is currently in progress for the C( )/ARC Intercommunication System Control. This

effort is being conducted to increase the cross-talk isolation in the communication system, reduce system distortion through the use of non-clipping audio limiting, and modifications to interface the new microphones into the system. This system has been proposed for use in the UTTAS and CH-47M aircraft. A second version of this improved intercom is being designed to provide an IACS compatible intercom system for new production aircraft. This unit will include independent radio level adjust controls.

A program is in process to develop a flat-response, improved noise reduction headset. This headset will consist of an aviator's helmet, and will improve speech intelligibility and acoustic penetration. Models of the improved assembly will be available for evaluation in the 4th quarter FY77.

An exploratory hardware contract for the multiple notch filter was awarded in FY76 with hardware delivery scheduled for late FY77. Primarily engineered for use in the high-noise environment of the CH-47, this filter will be capable of suppressing at least five noise peaks to reduce the amplified acoustic noise of the aircraft, improving speech intelligibility and reducing the noise transmitted to the ear by the communications system. This filter will be tested for potential application in other Army aircraft to eliminate characteristic turbine and transmission noise.

MULTIFUNCTION/INTEGRATED USE OF EQUIPMENT

To exploit the multifunction and integrated use of the tactical VHF-FM radio, product improvement and development programs are being pursued.

Current PI programs include a short circuit protected power supply and a broadband noise reduction transmitter modification. The broadband noise effort will permit operation of several AN/ARC-114 radios in a single aircraft and will improve retransmission performance. Both efforts are in the final stages of engineering design. The Phase Front Homing engineering design effort was successfully completed. Neither the low noise nor Phase Front Homing improvements will be retrofitted into existing radios, however, PIP efforts to update the procurement data baseline, will be accomplished in FY78, so that future procurements of the AN/ARC-114 will include these features. The feasibility of using an aircraft FM radio equipped with Phase Front Homing as a low-cost hover and bearing sensor was established during FY76. Flight tests are currently in progress. The bearing sensor effort was initiated in FY77.

The next generation VHF/FM radio (SINCGARS airborne version) will include the following improvements and any new Army requirements: simplified packaging to reduce maintenance time, improved RFI, reduced transmitter noise level and Phase Front Homing, high operational temperature range, preset channels, compatible secure voice operation, and increased reliability. It will be smaller, lighter, ultra-reliable, be less vulnerable to enemy interference, easier to support and maintain, have continuous transmit capability and work with data/teletype facsimile equipment. Development is planned to begin in FY78.

ELECTRONIC COUNTER-COUNTERMEASURES

The Electronic Counter-Countermeasures (ECCM) program initially is directed to support the established Operation Counter-Countermeasure (OCCM) procedures to address the current enemy threat with existing on-board radios. The long-term ECCM goal will be directed toward the use of the airborne SINCGARS radio and the application of such ongoing future TDMA programs as JTIDS, PLRS, and Packet Radio.

One applique approach being considered is the use of a Steerable Null Antenna Processor (SNAPAC). The SNAPAC involves investigating Steerable Null Antenna Processor technology for application to airborne communications. Primary emphasis is on techniques that could be utilized with existing narrowband radio sets. Technical barriers include rotor blade modulation, tracking speed, and signal acquisition/identification. These problems are being investigated under a contract which will result in a design plan for SNAPAC. As part of the program, a Steerable Null Processor (intended for ground applications) has been installed in a UH-1 and static ground tests completed with the rotor blades rotating; limited flight tests have also been conducted.

ANTENNAS

Present antenna programs are directed toward the establishment of a new technical data base for aircraft antenna performance for aircraft flying in the nap-of-the-earth (NOE) and ECM environments. This effort will cover computer modeling of different aircraft to determine optimum antenna locations and antenna

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test range validation of these models; design test, and evaluation of ECCM Adaptive Antenna and Steerable Null Antenna Processor appliques to the airborne VHF-FM radio; feasibility design and test of a SINCGARS compatible airborne coupler/antenna; and investigations of advanced flush-mounted/aircraft integrated and multifunction antenna techniques (i.e., strip line, cavities, multiple-band antenna, efficient low profile high power radiators, etc.).

NAVIGATION

GENERAL

The Army's air mobility mission has generated a need for aircraft to establish their position wherever they might be employed; to determine velocity, attitude, and heading for fire support, surveillance, and intelligence missions; and to navigate reliably and accurately under adverse weather and day/night conditions. Navigation systems may be divided into three general types: self-contained, externally referenced, and hybrid. The Army has the following navigation systems in the inventory:

- Self-contained
  - AN/ASN-86 inertial system
  - AN/ASN-64 Doppler (with AN/ASN-76 heading reference)
  - AN/ASN-43 heading reference (with airspeed indicator and hand-held map)
- Externally referenced
  - AN/ARN-89 ADF
  - AN/ARN-82A VOR
  - AN/ARN-103 TACAN
- Hybrid
  - AN/ASN-86 (with AN/ARN-103)
  - TACAN/Inertial

These systems have various shortcomings. The first listed self-contained system weighs about 100 lb, costs as much as $250,000, and has low reliability. Externally referenced systems now being used are subject to interference from enemy and weather (ADF), are restricted to line of sight (VOR, TACAN), and are inadequate for tactical positioning (ADF or VOR). The hybrid system is heavy, expensive, and has low reliability.

To fight and survive in modern war, helicopters must fly terrain (NOE) at night as well as during the day. For flat or rugged areas, full 3-dimensional navigation (NAV) is needed instead of the purely horizontal positioning of conventional NAV systems. In addition to the third dimension (3-D), however, NAV at NOE faces the greatest NAV anomalies (magnetic, gravity, radio) and natural and man-made hazards; time to identify and correlate checkpoints with maps is at a minimum; and NAV accuracy for joint air-ground operations is at a premium due to limited inter-visibility. At the same time, NAV system cost is limited by the large number of Army helicopters and their low-cost compared to Air Force and Navy fixed wing aircraft; and reliability must be high to ensure NAV continuity.

PROGRAM OBJECTIVES

In the operational environment noted above, Army aviation navigation R&D objectives for the three systems are:

- *Self-contained* – Reduce cost and weight by 66 percent and increase reliability by 100 percent while achieving an accuracy of 2 percent of distance traveled for ground-velocity-based systems and 1 n.mi./hr for inertial systems.
- *Externally referenced* – Overall system objectives, dealing only with radio systems (GPS, PLRS, OMEGA, LORAN), stress the very high accuracy inherent in these systems, increasing reliability, reducing cost and weight, and making the system as secure and effective as is possible in an EW.
- *Hybrid* – The R&D goal is to provide superior performance and invulnerability with minimal increase in cost and weight.

One benefit of a hybrid is that greater capability can be attained than exists in any single sensor for those missions with the most stringent requirements. Hybrids also offer backup not available with single-sensor systems, affording such advantages as the ability to operate effectively in spite of interference (intentional or unintentional) with externally referenced systems such as Global Positioning System (GPS) satellite navigation or PLRS Time Division Multiple Access positioning networks.

Also, with the hybrid technique the high position-accuracy external reference system can calibrate the self-contained system in flight by Kalman filtering. This updates self-contained system accuracy, and if

the external reference system is jammed, etc., the self-contained system can continue independently with a higher order of accuracy on a tactical mission.

To achieve 3-D NAV in the severe NOE environment, it is planned to provide current Army NAV systems with 3-D capabilities rather than developing still another NAV system at great cost and time. The 3-D NAV enhancement process will be evolutionary, that is, low-cost, lightweight, sensor/processor/display building block technique using new magnetic, radiation, and NAV-computer technology to fit basic architecture of current NAV systems; then, the 3-D capabilities will be incorporated as product improvements in fielded NAV systems.

PROGRAM STATUS

Self-Contained Systems. A new inertial navigation system is being developed, using the state of the art, to meet Army Special Electronic Mission aircraft tactical requirements. The Army and Air Force are engaged in the joint-development of a standard lightweight inertial system which would be far less costly, and more accurate and reliable than the present inertial systems used by the Army and Air Force.

The development approach is to configure an inertial navigation system designed to meet a form-fit-function specification with mission equipment employing a MIL-STD-1553A multiplex data bus interface. As part of this approach, the feasibility of new approaches to inertial navigation, such as strapdown, which promises to lower the cost and increase the reliability, is being investigated. Candidates are systems in development for other services such as the Navy laser gyro and the USAF MICRON systems. The planned IOC date is early 1980s.

The AN/ASN-128 Doppler was developed by the Army as a low cost, low-weight system that is a marked improvement over the AN/ASN-64. The engineering development of the AN/ASN-128 (XE-1 and XE-2) Doppler navigation sets was successfully completed. PQT-C, PQT-G, OT-II, DT-II testing was completed. A production contract was awarded to the Singer Corporation for 200 systems (AN/ASN-128(XE-2)) with a 300 percent option. Deficiencies and shortcomings revealed during testing have been corrected. These corrective actions will be evaluated during the initial production testing (IPT). The initial production quantity (200) in earmarked for UTTAS and COBRA (AH-1S) aircraft. The IOC date of the AN/ASN-128 for the UTTAS aircraft is August 1978.

Meanwhile, Doppler technology is being up-dated as a follow-on to the present program for further cost reduction in this area. Another candidate being investigated is radiometric ground-velocity sensing. This passive sensor offers the potential of high accuracy with low cost and weight.

The flight-test evaluation of Heading Reference Units (HRU) is a continuing program. Its purpose is to determine the performance of HRUs that are presently available against our aircraft mission requirements to determine whether cost-effectiveness of the Army's HRUs can be improved. As part of this effort, an engineering effort (analysis through UH-1 flight tests) was performed to investigate methods of improving the accuracy of the AN/ASN-43 HRU. Based on an evaluation of the test results of various modification approaches, a product improvement program was approved to build a brass board of the improved HRU to demonstrate improved dynamic accuracy, self-calibration, and BITE. At the conclusion of the brass board tests (laboratory and flight), 15 production prototypes will be fabricated for operational and environmental testing, including reliability. These improved HRU units will be deployed with the initial AN/ASN-128's in UTTAS.

Externally Referenced Systems. The Global Positioning System (GPS) under development as a joint DOD program is expected to demonstrate system operation in 1978. Manpack, vehicular, and airborne equipment are in the final phase of advanced development and were initially tested on the inverted range at Yuma, Arizona in 1977 followed by satellite signals at Yuma, Arizona and Fort Belvoir, Virginia. Engineering development is scheduled for February 1979. GPS shows considerable promise as both a stand-alone system as in the case of a manpack set and as a navigation sensor in the case of the airborne set. Horizontal and vertical accuracies of 4 m are anticipated. Improvements in antenna design are under study by ECOM to increase resistance to EW. Other R&D efforts are directed toward crystal oscillator stability improvement, multipath effects, and IMU integration techniques. Improvements in GPS link margin are necessary to ensure uninterrupted operation in foliage and to reduce multipath effects in unfavorable terrain.

The position Locator Reporting System is a Time Division Multiple Access System that operates in the UHF band and is capable of providing the integrated functions of position location, navigation, identification, and communication. It utilizes spread-spectrum, frequency hopping, error detection and correction, and encryption to provide optimum EW protection. Under Master Unit Control each user unit (airborne, manpack, and vehicle) is capable of being an integral relay to achieve over-the-horizon communication with the master unit.

The LORAN Airborne Navigation Subsystem (LANS) AN/ARN-114 is no longer considered the common airborne positioning and navigation subsystem for fleet-wide application. A limited quantity of AN/PSN-6 manpack LORAN receivers are being procured primarily for tactical and doctrinal formulation purposes. These will also be available in the event of a contingency; for this purpose, the Army continues to participate to a minimal extent in the Air Force funded ECCM program. If the contingency arises, and DA so directs, the equipment modifications developed by this program can be retrofitted into the existing AN/PSN-6 manpack receivers.

The approach toward achieving 3-dimensional positioning and navigation is to enhance current Army navigation systems with 3-dimensional capabilities. This will be accomplished by evolving low-cost, lightweight, sensor/processor/display building blocks, and by using new radiation, magnetic, and inertial sensor and microelectronic techniques to fit the basic architecture of current NAV systems. Three-dimensional capabilities will be incorporated as product improvements for fielded navigation systems.

Doppler navigation systems are in production for the Army and inertial, satellite global positioning, and time division multiple access positioning and navigation systems are being jointly developed by the services. However, all of these systems are two-dimensional UTM or latitude/longitude navigation systems. For three-dimensional navigation, a number of inputs already exist in adequate, affordable form for adaptation to current navigation system architecture (such as ground velocity along-track and cross-track; relative wind and air speed; pressure, temperature and torque sensors; fuel amount and rate; and a map display which is slewable). Experimental wire- and forward-terrain-obstacle sensing units have been built and are undergoing extensive testing.

However, the outputs for full 3-D position and navigation do not exist nor do the means for their most effective display to the air crew. Therefore, the 3-D NOE positioning and navigation program aims to develop the additional 3-D navigation inputs required, at affordable cost, along with the data-processing and display essential for the 3-D navigational outputs. Of the specific building blocks identified for 3-D positioning and navigation, a basic NAV system architecture has been established through the lightweight doppler NAV system and Loran developments; a ground velocity capability has been developed; the concepts for "altitude limit/margin" have been established experimentally; relative wind/air speed sensors down to low-speed regions are being tested and comparatively evaluated; existing map displays are being evaluated for Army application; and wire- and forward-ground-sensors are under test.

Work is now under way on the magnetic heading reference units to reduce the error this area now yields in NOE navigation, and on increased reliability/reduced cost NAV computation techniques:

- To derive vertical rate from the ground velocity sensor
- To incorporate the altitude limit/margin concept
- To determine fuel-range and time-to-burnout from input fuel amount/rate, altitude margin, and true wind calculations referred to mission path
- To incorporate navigation updates with map display slew inputs.

Hybrid Systems. The development of GPS and PLRS sensor models and optimal and suboptimal combining algorithms for HRU, GPS, PLRS, Doppler, and Inertial Hybrids will be continued, including hardware verification and flight tests. Also, new inertial and velocity sensors will continue to be investigated for their application to hybrid systems (such as ring laser gyros, microwave radiometric velocity detectors, and nuclear magnetic resonance systems). Joint service testing was completed on hybrid Doppler and air data navigation systems with TDMA positioning networks. Results of this effort are in the process of publication.

The GPS Joint Program Office (JPO) plans to prototype a GPS set in the next phase (engineering development) which will be totally integrated with

the doppler. The intent is to replace the Doppler CDU/processor with a GPS/Doppler control display of the same form factor. The Doppler processing will be performed in the GPS data processor. Integration will be effected to optimally utilize the navigation information from both sources. The GPS will improve the accuracy of the Doppler, and the Doppler will permit navigation during short periods of GPS signal loss due to jamming. ECOM is assisting in preparing the interface specifications for integrating this prototype into the Army DT/OT II aircraft for testing.

Secure Navigation. The Army and Air Force, in a joint program, have developed and laboratory tested a secure, pseudo-randomly coded, RF modulation technique for use as an ECCM against replica-type deceptive jammers. Tests have shown that the new coding technique not only precludes spoofing of LORAN receivers but also improves performance against pulsed and synchronous CW interferers in both the hard limit Army manpack receiver (AN/PSN-6) and the hard limit/linear Air Force receiver (AN/ARN-101). The Air Force will continue field validation of the new pseudo-random coding technique during FY77 and FY78. ECCM requirements for inertial type hybrid navigation systems were established in FY77 and will be further refined and implemented during FY78.

ECCM requirements have been established for Doppler navigators based on preliminary EW vulnerability estimates. Field tests were conducted to verify key aspects of the theoretical assessment. An EW vulnerability assessment of airborne receivers for the Global Positioning System was initiated. An investigation to optimize hybrid navigation systems in an EW environment was also begun.

PRODUCT IMPROVEMENTS

Although no R&D is involved, various degrees of VOR, ILS, and DME capabilities are being incorporated into many in-service aircraft (e.g., UH–1, OH–58, AH–1, CH–47, CH–54, UTTAS, T–42, U8D, U8F, OV–1, and U–21). This civil airway navigation capability will meet the new FAA split-channel requirements for Europe and the U.S. as well as the requirement for inadvertent IFR capability. New small, lightweight, reliable, and inexpensive commercial-type equipment is being procured for this purpose. The equipments are being covered by a reliability improvement warranty relieving the Army of organic maintenance requirements. The VOR/ILS equipment is ready for release pending conclusion of U.S. Army Test and Evaluation Command testing. It is anticipated that the DME will be under contract by June 1977. By using an existing commercial design and minimizing MIL-SPEC requirement usage the equipment can be produced at very reasonable prices.

TACTICAL LANDING

GENERAL

Tactical landing refers to Army aircraft conducting landing approaches to very low heights or to full touchdown landings under nonvisual tactical conditions. Since man's first attempts at nonvisual approach and landing, the primary technique has been to establish a reference descent path in space through radio signals from ground equipment. In the case of GCA (Ground Controlled Approach), the ground equipment is a radar set, and ground-derived aircraft position data are used to steer the pilot by voice or data link. In the case of ILS (Instrument Landing System), the ground equipment radiates beams that, in themselves, form reference descent path signals in space. In ILS, a cooperative airborne receiver converts these ground-radiated signals to steering information that is displayed to the pilot on cockpit instrumentation. In both GCA and ILS, the aircraft is constrained to fly a specific path to a specific point, the safe location of the descent path having been carefully predetermined by ground personnel. The ultimate tactical landing capability is seen as deriving from a technique in which all equipment is self-contained on-board the aircraft, and no assistance is required from ground personnel or equipment.

After nearly 50 years of landing systems development, the state of the art now provides nonvisual landings to decision heights of 200 ft and Runway Visual Range (RVR) of 2,400 ft (the civil category I landing) with both GCA standard VHF/UHF ILS under the "see to land" concept (i.e., visual aids and lighting are provided to aid the pilot in executing a visual landing after a nonvisual approach to a point 200 ft above the landing site). While several standard ILS-equipped airfields and some aircraft have been certified for category II landings (a decision height of 100 ft and a RVR of 1,600 ft), category II landings are presently not an operational reality for Army helicopters. Several microwave ILS techniques, evolved over the past decade, are vastly superior to standard VHF/UHF ILS because their spatial beams

are formed completely by antenna apertures of reasonable dimensions and do not depend on favorable ground reflection to develop flyable signals in space. The FAA has selected a 5-GHz Interim Microwave Landing System (IMLS) to provide landing guidance at those sites where terrain conditions prohibit the installation of conventional VHF/UHF ILS. Decision heights of the IMLS will typically be category I. Also, the Navy authorized a 200-ft decision height aboard aircraft carriers with a 15-GHz scanning beam system very similar to that being developed under the Army TLS (Tactical Landing System) program. Technical barriers to realizing an Army tactical landing capability with an ILS involve establishing safe landing guidance in adverse terrain and solving the instrument-to-visual transition problem peculiar to the steep approach angles of the helicopter and austere landing sites. With regard to the self-contained landing capability, several image-forming sensor techniques (radar and infrared) have been investigated. While a degree of capability has been demonstrated, no technique accomplishes all of the functions required of a self-contained landing system; that is, to locate and positively identify the landing point with no assistance from the ground, establish an obstacle-free descent path, provide guidance information with which the pilot can execute the descent to or below visibility minimums existing at the site, and indicate any system malfunction that would jeopardize acceptable completion of the landing.

TACTICAL LANDING OBJECTIVES

The primary R&D objectives in tactical landing are:

- To generate usable microwave guidance to well below the category II decision height of 100 ft for the full range of descent angles negotiable by fixed-wing and rotary-wing aircraft in adverse landing sites.
- To ensure maximum system immunity to degrading multipath effects and generate guidelines for system operational deployment.
- To determine minimum night/IFR, visual-aid/lighting requirements for the breakout-to-touchdown segment of the landing.
- To examine decelerated approach breakout transition problems for effective use of guidance below the 100-ft decision height.
- To ensure that Army needs are incorporated into the National Microwave Landing System (NMLS) under development, since it is anticipated that the national program will adopt a new common civil/military signals-in-space standard (replacing the standard ILS).

New capabilities to be investigated include the use of advanced cockpit displays and control systems for decelerating approaches along straight-line and curved-descent paths, high-density landings with aircraft separations of but a few thousand feet, and automatic landings. No current effort is under way specifically addressed to solving the self-contained landing system problem. The intent is to concentrate on realizing an actual IFR capability with the cooperative microwave TLS and then to apply that experience in a search for promising approaches to the self-contained problem.

TACTICAL LANDING PROGRAM

The present TLS development provided ground, airborne, and test equipment for developmental and operational testing in the first quarter of FY75. Equipment for the UTTAS prototype aircraft was provided in the same time frame. DT II/OT II testing of the TLS was completed in the 2nd quarter of FY76. The DEVA IPR was held in the 4th quarter of FY76. A decision to terminate the TLS program was made based on Army support of and plans to procure the tactical versions of the National Microwave Landing System and the user has stated that there is no requirement for an interim tactical landing system.

The National Microwave Landing System Program is a joint DOD, DOT, and NASA effort, with the FAA as the lead agency. In December 1974, a technical evaluation team recommended a provisional system technique/signal format for adoption as the US standard. This format will be tested by each of the user agencies using hardware to be developed in the following phase of the program. Final ratification and evaluation will start in FY78. The FAA entered into a contract definition program for military MLS equipment in FY7T. This led to a joint service evaluation of proposals for military MLS hardware with contract award scheduled for FY77. Internal flight research efforts in support of the MLS have demonstrated the potential for performing both manual and fully automatic steep angle, decelerated, helicopter approaches to a hover using relatively unsophisticated airborne flight director displays, automatic flight control systems, and flight path couplers. In FY77, this effort was extended with a user/developer agreement for the

user to conduct a Tactical Instrument Steep Approach and Landing (TISAL) Concept Evaluation Program (CEP). This CEP will examine the full operational implications of low visibility tactical landing approaches, for example, instrumentation requirements, instrument-to-visual transition problems, and avionics system redundancy/integrity aspects. Additionally, the ability of candidate MLS equipment to provide high-integrity guidance in a high-density helicopter landing environment is being studied with respect to determining a feasible method of integrating MLS with the Air Traffic Control and Beacon Reporting System (termed the cross-banded system). Also a High Density Landing Simulation is being developed to investigate whether an air traffic controller can manually handle and control high density helicopter traffic, with a spacing on the order of 2000–3000 ft under IMC conditions in the tactical terminal area. These small aircraft separations appear realizable given the very slow aircraft speeds that result from decelerated helicopter landings, the feasibility of which has been experimentally established; the concept is presently being evaluated by the user under the TISAL CEP discussed above. The potential of the cross-banded system to serve as a transportable, terminal ATC facility will be investigated. Also, in FY77 a small Ku-Band ground landing system will be developed to help resolve the C/Ku-Band MLS issue, and a landing display effort will be initiated to achieve simplest configuration for decelerated approaches.

The Army will use the TLS and NMLS programs to establish a sound basis for generating a fleet-wide tactical instrument landing capability. To date, results indicate that TLS will serve all Army aircraft with sufficient guidance to instill pilot confidence quickly. While initial operational capability will probably be set at a 200-ft decision height, the guidance provided by TLS (unlike standard ILS) will be usable well below a decision height of 100 ft, so that increased operational capability will derive from evolutionary improvements in displays, piloting skills, visual aids, etc. The NMLS program promises a mechanism for achieving fully compatible operation among the military services (and civil aviation as well). Because of the basic similarities between the TLS and NMLS concepts, Army experience and capability derived from TLS will be directly applicable to NMLS. The self-contained instrument landing problem, for which initial investigations are to begin in FY79, is an extremely difficult one. The risks involved in achieving a true solution are high, but acceptable, because the derived capability will be militarily attractive and rewarding.

ECCM FOR TACTICAL LANDING

An EW vulnerability analysis of the NMLS has been completed. The results of this analysis and subsequent field tests will be used to derive ECCM requirements for the Army tactical version of the NMLS.

AIR TRAFFIC MANAGEMENT

GENERAL

An air traffic management system is required to facilitate the safe, orderly, and expeditious movement of cooperating aircraft in the tactical area of operations, and to enhance interface with other airspace users. It consists of air traffic management procedures and equipment that allow the commander flexibility in the employment of his combat assets. The movement of all aircraft (during departure, enroute travel, approach to terminal, and landing) will be regulated as expeditiously as possible with minimum restriction to aviators under varying conditons of weather and visibility.

To provide an air traffic management system for aircraft use under conditions that prevail in the battlefield (i.e., high air defense threat, nap-of-the-earth flight, and high flexibility of use under conditions of poor weather and visibility) is a very challenging problem. Under the present system, the see-and-be-seen principle is the primary hazard avoidance technique. This principle requires constant vigilance by aircraft crews, since controllers can only provide alerting information to cooperating aircraft, based upon voice position report data evaluation. The system becomes saturated at very low aircraft densities during poor weather conditions. A system of flight operations centrals and terminal control facilities tied together by voice radio techniques is now standard in the Army.

CONCEPTS AND APPROACH

The next level of air traffic management to be introduced into the Army will use real-time aircraft position data obtained from radar in conjunction with aircraft position based upon voice reporting. Current Army aircraft management principles and policies, user requirements, and restrictions imposed

upon aircraft operations in the Corps area by the high threat environment have resulted in the present Army concept. Under this concept, air traffic control flight clearance under Instrument Meterological Conditions in the Corps area is to be initiated with and received from the Flight Operations Center via the Air Force Control and Reporting Center. From Division rear, forward to the FEBA, the Army plans to furnish Air Traffic Management services via the Flight Coordination Center and the nondirectional beacon. An inconclusive area, still a technical barrier in air traffic control technology, is air-ground-air communications under NOE flight conditions. Further development is needed to determine the best technical approach to maintaining data communication over the horizon with low altitude aircraft.

CURRENT AIR TRAFFIC MANAGEMENT

Current engineering development efforts for the terminal subsystems of the Air Traffic Management System include the visual control facilities, AN/TSW–7A and AN/TSQ–97. The AN/TSW–7A is a three-man control tower used at major tactical airfields. DT II/OT II testing was completed in FY75 and the planned IOC date in FY79. Future AN/TSW-7A fabrication will incorporate a new antenna which is smaller and less costly than the existing antenna yet provides the same in performance. The engineering development of the AN/TSQ–97, a man-portable control facility to be used at forward tactical airfields, was completed in FY74. In FY75, low-rate initial production was started. The planned IOC date is FY80. As part of the overall Air Traffic Management System (ATMS) improvement program, the Flight Coordination Central, AN/TSC-61 is being updated to include new communications equipment. Fabrication of these equipments is being done at the Tobyhanna Army Depot with plans for 14 production units to be delivered by FY79. These systems will provide tactical enroute air traffic control and airspace management facilities in support of Army Aviation elements in the combat zone. The improvement of the Landing Control Central, AN/TSQ-71, instrument approach and communications capabilities at tactical airfields was initiated in FY73 through a product improvement program (PIP). This PIP modifies the GCA Radar, AN/TPN-18 for improved RAM characteristics. In addition, a PIP was initiated in FY76 that updates the UHF/VHF radios/antennas for increased frequency channel availability. The modified AN/TSQ-71 units are to be fielded in FY80.

In FY76 a computer simulation effort was initiated which is to provide insight into the problems associated with the management of high density Army air traffic in the terminal/tactical environment. This effort will provide system engineers with design information unique to Army air traffic for incorporation into future Army ATM systems/concepts. The on-going computer simulation effort incorporates scenarios with interactive pilot/controller displays for investigation of separation requirements for closely spaced helicopters performing decelerated and non-decelerated approaches and landing in a tactical environment under conditions of IMC. This is a totally unexplored ATM problem unique to helicopter operations, particularly as applied to tactical, airmobile operations.

In response to newly emerging concepts expressed in Draft FM1-60 "Army Air Traffic Management in the Combat Zone" (September 1975), a program was initiated in FY76 to provide Very Lightweight Air Traffic Management Equipment that will allow ground personnel to determine the range and bearing from their position to selected aircraft. With this information they will be able to assist aviators by giving them steering and distance information when required. Examples of such use are: vectoring aircraft to an LZ or forward area resupply and refueling point under poor visibility or darkness conditions; sequencing flights into an area in the most expeditious manner; and monitoring traffic in the vicinity of an airfield. The equipment will range in size and capability from very light units which work with one aircraft at a time up to larger units, about 10 ft^3 in size, which would be used at Division Airfields to track large numbers of aircraft. An example of a very lightweight unit would be a hand-held device with which one man can vector a medevac helicopter to an isolated position to pick up a wounded man. This equipment will operate by interrogating the aircraft's existing transponders, thereby not requiring new or additional equipment in the aircraft. The various equipment will be compatible, and functional modules will be interchangeable in order to reduce maintenance and logistics costs. The equipment is scheduled for delivery in the 4th quarter of FY77 and will undergo engineering tests and user evaluation during the first half of FY78.

LONG-TERM ATMS

Programs utilizing the concept of ICNI/TDMA (Integrated Communication, Navigation, and

Identification/Time Division Multiple Access) are being examined for their potential capability to provide more effective Air Traffic Management Systems in the post-85 time period.

This concept of combining many of the functions now performed by separate systems in a single multi-function system will provide such services as precise position location, data communication, IFF, and collision avoidance. This system concept is uniquely suited to implementation by stages. Once the basic system is developed, additional functions can be realized – mainly by software changes. Growth capability can thus be tapped in accordance with future user needs and funding constraints. ICNI could provide many advantages to the Army:

- Accessibility – ICNI will provide a common relative grid where data of common interest may be transferred among all interested parties with a maximum time lapse of only a few seconds. This capability for rapidly establishing and exchanging position and identity will prove invaluable in future tactical operations involving a mix of friendly and enemy aircraft and other highly mechanized weapon systems.

- *Commonality* – Multiple functions can be accomplished with common basic modules using a commonly shared RF channel.

- Security – The digital structure is well suited to the application of anti-jam and security measures.

- Performance – The use of common equipment to perform multiple functions increases the effective payload of a given aircraft.

- Logistics – The reduction in the number of electronic equipment required by this approach and the possibilities for simplified (semi-automated) diagnostics and repairs greatly ease the problem of logistics and support.

The feasibility of a first-generation ICNI system combining position location and data transfer functions has been established through a joint development, test, and evaluation program conducted by the Army and Marine Corps. This system, identified as the Position Location Reporting System (PLRS), entered Engineering Development in July 1976. The DT II/OT II is scheduled to start in mid FY78.

ENVIRONMENT SENSING

GENERAL

Environment sensing provides for sensing the environment external to the aircraft, as necessary, for safe operation of the aircraft and achievement of tactical goals. It includes equipment designed to provide a functional capability in radar altimetry, terrain avoidance/following, obstacle avoidance, collision prevention, formation flight, high-resolution ground-mapping, moving target detection and weapon pointing, weather warning, and assistance in making remote area landing approaches. Anticipated technology developments will enable increased levels of environment sensing capability in the advancing time-frame as reflected in the approved requirement documents. Environment sensing technology barriers are achievements of severe performance requirements (resolution, range, fields of view, etc.) within the practical limitations of size, weight, cost, etc., imposed by the Army's small helicopters.

RADAR ALTIMETER

The design development and production of the AN/APN-209 was undertaken to satisfy the Army's requirements for a standard lightweight militarized absolute altimeter with low acquisition and ownership costs. The competitive engineering development effort was a DDDR&E pilot "Design-to-Cost" program with only five essential parameters (altimeter range, accuracy, frequency, size, and RAM) and a Design-to-Cost goal of $3,500 in FY72 dollars.

After an extensive DT II/OT II test phase a production contract was awarded to Honeywell Corp. in June 1976 for 2000 systems at $200 under the Design-to-Cost goal (actual cost $4,622 Design-to-Cost goal; $4,828 inflated June 1976 dollars).

The system is optimized for low-level helicopter operations to provide accurate aircraft altitude in the 0–1500 ft range with both digital and conventional analog displays and *LO & HI* warning lamps. The analog display is designed primarily to provide the pilot with altitude trend information during forward flight while the digits are used during precision hover and sling load applications.

Pilot adjustable LO & HI warning lamps enhance system utility during high workload conditions and enable the pilot to set and maintain an altitude band

based upon terrain features and anticipated threat. The current 3-year multi-year contract with Honeywell contains a 4-year reliability improvement warranty and will satisfy the Army's initial requirement for OH-58C, UH-1D/H, CH-47C, and AH-1S aircraft with equipment deliveries beginning in the 1st quarter of FY78.

WEATHER RADAR

In order to retain a weather avoidance capability in Army fixed wing U-21 type aircraft, which has been deemed mission essential in the RU series aircraft, it is imperative that an immediate effort be undertaken to replace the aging and non-supportable AN/APN-158 with a modern lightweight digital weather radar. A recent field survey of current APN-158 assets revealed that existing systems are being supported through cannibalization since the manufacturer (Collins Radio Company) no longer makes the radar and is not producing spare parts or modules.

The present program for which Project Improvement Management Information Reports (PRIMERS) have been prepared, will be undertaken as an aircraft PIP for U-21 and RU-21 type aircraft. The program, which began in FY77 to define essential system parameters, is leading toward a two-step formally advertized procurement with a 5-year reliability improvement warranty and production award scheduled in FY79 for 175 systems with 100% production option.

MULTIFUNCTION ENVIRONMENT SENSOR

A need exists for a multifunction environment sensor to provide Army aircraft of the post-1980 time frame with a capability to perform low-level flight under night and adverse visibility conditions. The current technology base for such a multifunction capability is extremely limited, particularly in the individual areas of obstacle detection, collision avoidance, and all-visibility formation flight. The near-term objectives are to build up the technology base in each of the individual sensor areas and the area of multifunction sensors to a point where the technical feasibility of a multifunction environment sensor can be demonstrated and a qualitative spectrum of alternatives prepared. Establishment of feasibility for a full multifunction capability is forecast for FY82, with an IOC of approximately 1990. Individual sensor capabilities are anticipated with earlier IOC dates.

A major limiting problem in the area of low-level flight is the detection and avoidance of small wires and cables. A scanning CO_2 laser system, the Laser Obstacle/Terrain Avoidance Warning System (LOTAWS), has demonstrated in flight tests the detection of 1/8-in. wire at ranges of 1500 ft and detection of transmission lines at ranges to 1 mile, with a secondary capability for terrain following. In FY77 additional exploratory development has addressed the addition of other functional capabilities to LOTAWS, including hover augmentation, rangefinding, and target designation, with a view toward providing a more cost-effective total system capability. During FY78 flight tests will be performed to demonstrate the technical feasibility of this system to accomplish a variety of airborne tasks. An EW vulnerability investigation of the LOTAWS has been completed and will provide the basis for formulating ECCM requirements for future LOTAWS models.

Investigations of alternative obstacle avoidance systems have identified the use of charge coupled devices (CCD's) as having considerable potential as a lower cost solution. A contractual effort began in late FY77 to design, fabricate and ground test a flyable exploratory development model of a wire obstacle warning system based on a CCD approach. The design and fabrication phases of the program are scheduled for completion in FY78 with testing to follow.

A LOA for Improved Lighting System for Army aircraft is being prepared by TRADOC and DARCOM. This LOA includes a requirement for covert nighttime formation lights of a type previously investigated. Upon successful staffing and funding of the LOA, a program investigative effort into the requirements of the LOA will be initiated.

An exploratory development effort to exploit the technology inherent in the Army developed AN/APN-209 Radar Altimeter, Collision Warning System (CWS) and Proximity Warning Device (PWD) to provide additional functions for homing, rendezvous, formation flight/station-keeping assistance, and landing assistance was initiated in FY77. This effort, the multifunction transponder, will provide all of these functions in a single multifunction unit configuration. This will result in considerable reduction in

size, weight, and cost as compared to current capability, where each function is performed by a separate black box.

PRODUCT IMPROVEMENT PROGRAM

A Product Improvement Program directed toward reliability improvement and technical update of the initial production Proximity Warning Devices was initiated in FY77. Basis of PIP are initial production models declared excess to Ft. Rucker's requirement. These models will be improved and subsequently distributed to meet PWD requirements at Forts Hood, Campbell, and Bragg.

INSTRUMENTATION

GENERAL

Instrumentation provides for the display of information to the pilot on the status, condition, and trend of essential parameters and subsystems necessary for the safe operation of the aircraft system and the achievement of tactical goals. This information includes data on flight, airframe, and subsystem parameters, navigation and radio aids, landing aids, etc. The display of computed director information for specific functions or maneuvers such as IFR, steep angle approach and landing, and terrain-following would also be accomplished using aircraft instrumentation. The majority of instruments in today's helicopters are based on the technology of fixed-wing instruments that do not address the special requirements of rotary-wing aircraft. Although early development work has been done for specific helicopter instrumentation (such as vertical format engine indicators, flight directors, head-up displays, and emergency warning indicators), there has been a lack of formal requirements documents and funds to procure, test, and evaluate the potential of these systems.

The basic instrumentation R&D objectives are to provide instruments and displays best suited for helicopter operations during day, night, and instrument flight conditions. These objectives support aircraft low-level operations, observation and fire support missions, air traffic control, takeoffs, hover, and approaches and landings. When earlier fixed-wing work provides a viable base for expansion into the rotary-wing regime, fixed-wing systems would be adapted, modified, and expanded as appropriate to the specific application.

The current instrumentation programs are as discussed below:

- Control Display Unit – The CDU will be programmable and compatible with Air Force Multiplexing Standard MIL-Std-1553. The CDU is intended to replace control units for single subsystems such as ARC–164, –114, LORAN or Doppler Control Unit or to be programmed to function as a control unit for several units such as the DIMAP core system. The panel will employ an alpha-numeric display and multi-legend display switches capable of operating under extreme cockpit illumination conditions. Growth capability will be provided through the use of modular packaging of the electronics. Work was initiated in FY77 using the technical and procedural results of the I/O Panel Display for Digital Modules Avionics Program (DIMAP). A program to procure advanced development models will begin in FY78 to demonstrate full system potential by FY79. The operational impact of this effort is to greatly reduce the console space requirements and simplify operation.

- *RMI/HSI (Digital Solid State)* – As digital sensors and bus systems are increasingly employed, their utilization will be severely limited by the existing electromechanical-analog instruments. A feasibility investigation of a solid-state radio magnetic indicator/horizontal situation indicator (RMI/HSI) to serve as a digital replacement for conventional electromechanical indicators was initiated in FY77 and will continue in FY78 culminating in the delivery of a feasibility demonstration model.

- *Integrated (Solid State) Multifunction Display* – A program to explore the maximal usage of digital solid-state technology for an integrated display will begin in FY78. Coordination with other activities such as HEL and TRADOC will concentrate on the establishment of coordinated programs and goals. The contractual portion will be a study and design stage to include prioritization of display modes, formats, and functions in the context of user requirements, and the completion of a preliminary model design.

- *Programmable Symbol Generator and Multifunction Display* – The PSG/MFD procured in FY76 was used to evaluate the DIMAP core

system and was continued in FY77 with contractor field support for integration of the equipment into the test aircraft after the DIMAP bench testing. An additional stroke-written display plus software necessary for interfacing the PSG with a teletypewriter enabling ground test and verification of our software program for varying display formats will be started in FY78.

SURVEILLANCE AND TARGET ACQUISITION

GENERAL

Surveillance involves the detection of weapons, personnel, vehicles and fixed installations, and conducting radiological surveys and assessing damage and terrain conditions. Target acquisition is a refinement of the surveillance process involving the location of selected targets with sufficient accuracy so that they may be taken under fire by weapons. To overcome the obstacles of distance and interfering terrain, a large part of the surveillance and target acquisition mission must be accomplished by aerial means.

The Army's capability to perform aerial surveillance is presently provided by the OV–1D Mohawk system. This second generation Mohawk uses interchangeable, high-resolution IR linescan and sidelooking radar sensors to provide a day/night surveillance capability. This capability is good for intelligence applications except for lack of an air-ground data link (still under development) to permit ground viewing of sensor data in real time. However, the OV–1D Mohawk provides only a very limited target acquisition capability. Its principal deficiencies for this function, beside the lack of real time data on the ground, are a relatively slow search capability and low accuracy in locating observed targets.

SURVEILLANCE AND TARGET ACQUISITION REQUIREMENTS

The following improvements are required in airborne surveillance and target acquisition capabilities, beyond those provided by the OV–1D Mohawk:

- Detection of targets under the cover of foliage.
- Faster coverage of an enemy area and quicker detection of changes in enemy activity, including means for transmitting airborne sensor data to ground receiving stations in real time.
- Better resolution of day/night sensors for better target identification.
- Real-time transmission of surveillance and target acquisition data, in a jamming environment.
- Increased ability to penetrate the enemy for purposes of surveillance, target acquisition, and target designation.
- Precise location of targets, so that weapons can be effectively directed to destroy them.
- Tracking of ground targets, which are designated by a laser beam, by an airborne seeker.

SURVEILLANCE AND TARGET ACQUISITION PROGRAMS

The foregoing requirements are the objectives of the following programs as discussed below.

Standoff Target Acquisition System. This advanced development program developed a heliborne MTI radar with interactive ground display system to detect, locate, and track moving ground vehicles and low-flying aircraft beyond ground line of sight. An advanced development SOTAS has successfully completed field tests at Hunter Liggett Military Reservation, at White Sands Missile Range, in Korea, and in Europe during the 1976 Reforger field training exercise. The system also participated in 1977 Reforger exercises in Europe. The program is expected to enter the engineering development phase second quarter FY78. Future plans include fielding of two contractor supported systems similar to the AD model in FY78, and four engineering development models in FY81 to provide interim operational capabilities. The fully military-qualified production system is expected to be available in FY85.

Standoff Fixed Target Detection Radar. While many proven techniques exist for detecting moving targets, the detection of stationary, tactical ground targets presents a difficult problem. The SOFTAR program, initiated in 1975, is aimed at the development of techniques for the detection and classification of tactical ground targets at standoff distances (10–30 km) by means of radar on a low performance platform, such as a helicopter.

A program was initiated during FY76 in corporation with the Air Force Avionics Laboratory and Goodyear Aircraft Co. to obtain airborne signatures of target arrays in several environments. These measurements have now been completed and the results are being processed at ECOM. A 2-year stationary target detection and recognition study was also initiated during FY76 with the Georgia Institute of Technology. The major tasks of this study are concerned with: the review and analysis of existing target and clutter signature data obtained from various sources, detection and recognition algorithm synthesis, comparative evaluation of various detection and recognition algorithms leading finally to recommendations for the design of a standoff airborne radar with fixed target detection capability.

Millimeter Surveillance Radar for the Army RPV. A contractual effort with the Norden Division of United Technologies Corporation was begun in FY76 with funding provided by the RPV Weapons System Manager, AVSCOM. The contract provides for the design and fabrication of a brass board radar model, utilizing to a large degree existing components, in order to demonstrate the utility of the radar concept. The radar, operating at 3.2 mm (95 GHz), is designed to provide surveillance information under adverse weather conditions. The brass board radar gives a forward coverage of approximately $\pm 20^\circ$ over a 1 to 3 km range with 3-m range resolution. It provides high resolution ground mapping, fixed target enhancement, and MTI modes of operation.

The design and fabrication of the brass board model and a very limited ground test in a low clutter environment have been completed. More extensive tests, including tests in higher clutter environments, are required to properly evaluate the capability of the brass board radar. Research and development in the area of lightweight, low power-drain components is also required to provide the needed performance in a package compatible with employment on an RPV.

Photographic Systems. Product improvement of the Tactical Imagery Interpretation Facility (TIIF) has been initiated to upgrade the light table and provide human engineering of the facility. A portable field kit for imagery interpretation outside the parent facility will be procured.

Near real-time target detecting system for detection and analysis of targets in terms of their color signature is under development. It is envisioned that the system will detect camouflaged targets from the natural surroundings and transmit to the ground a detailed photograph of the target with code block information for location. The recent breakthrough in rapid color processing techniques has made the capability of near real-time transmission of color photography a feasibility.

The Tactical Imagery Processing Laboratory (TIPL) will be developed to replace the outmoded capability of the ES-38. This rapid-access mobile darkroom will utilize the latest advance technology in photographic equipment. Capabilities will include film processing rates of 40 ft/min and printing rates of 50 ft/min, dry silver reproduction, controlled temperature material storage and pollution treatment facilities.

A Mobile Army Ground Imaging Interpretation Center (MAGIIC) will be developed to replace the TIIF and will become the Army's imagery interpretation center. The MAGIIC will be compatible with the imagery interpretation facility of the Air Force and Marine Corps, since it consists of equipment developed for those services configured for Army needs. This will facilitate the rapid interchange and filing of all intelligence reports to provide all-source intelligence to the Commander.

A feasibility study to provide techniques for the development of a passive day-night, long-range standoff photographic surveillance system will utilize extremely long exposure times, which will eliminate the requirement for artificial illumination at night, and development of a stabilization device to provide the steadiness required for extremely long exposure times associated with existing light photography.

Dry Processing for AN/APS-94D Radar. The de-bugging of the prototype model of the dry silver film processor has been completed and the production of the equipment is now under way. The first production model will be delivered about June 1978.

Interim (SLAR) Data Link. A modified AN/UPD-2 UHF interim data link was deployed to Korea in December 1976 and will be used to transmit AN/APS-94D radar data to ground terminals. This data link will be replaced by a solid state digital link which is expected to be fielded in FY80.

Laser Designator/Tracker System. Development of this system, AN/UAS-8, is complete. It consists of

two separate units, an Airborne Laser Tracker (ALT) AN/AAS-32 and a Laser Target Designator (LTD) AN/PAQ-1. The designator is used by forward observers to designate area targets. The tracker is installed in mission aircraft and coupled to a visual display to guide the aircraft to the target being designated. The LTD completed DT II/OT II during the 2nd quarter of FY77. The ALT completed DT II during the 2nd quarter of FY77.

Hand-Held Laser Range Finder AN/BVS-5. The HHLR is under development to provide the target acquisition needs of both infantry and the artillery forward observer. For the infantry, the light weight of this equipment (5 lb) allows hand-held operation; for the artillery requirement, a tripod will be used. The clear day ranging distance of 10 km permits a high probability of an accurate first round delivered on target. The HHLR completed DT II/OT II in the 2nd quarter of FY77. A production award is planned for the 4th quarter of FY77.

Aerial Radiac System. The Aerial Radiac System (ARS) AN/ADR-6, now in development, will provide a nuclear detection and measurement capability in Army rotary and fixed wing aircraft. The operational altitude range is up to 1000 ft above terrain at aircraft speeds to Mach 0.5, based on ground radiation levels of 1–1000 rad/hr. DT/OT II were completed in FY76, including flight operations with the aerial radiac system operating in Mohawk (OV-1D) aircraft at White Sands Missile Range, New Mexico (U.S. Army Air Defense Board and TECOM). The AN/ADR-6 was capable of detecting and recording in flight the aerial radiation profiles from ground-based Co-60 sources. DT II test experience will result in several improvements in the Mohawk configuration of the AN/ADR-6 ARS, particularly as relates to ease of installation, access to electronic modules, and preflight checkout procedure. A development acceptance in-process review, held in October 1976, recommended type classification limited procurement and task progression into low rate initial production.

ECCM FOR SURVEILLANCE AND TARGET ACQUISITION

The following are specific systems and functional areas under investigation:

- *Standoff Target Acquisition System* – The EW vulnerability of the interim SOTAS is currently being assessed. Theoretical analyses have been completed and preliminary electronic countermeasure field tests have been performed. Data analysis is continuing. Analysis of an advanced SOTAS has been initiated.
- *Side Looking Airborne Radar* – Flight tests of the ECCM proposed fixes for the AN/APS-94D were completed in March 1977 and the data from those tests and other laboratory tests are now being evaluated. Production of prototype retrofit kits is scheduled for the 1st quarter of FY78.

NIGHT VISION SYSTEMS

GENERAL

Emphasis on aircraft survivability has given impetus to the need for night vision devices that will allow Army aircraft to perform their missions at nap-of-the-earth altitudes during darkness and periods of reduced visibility.

The primary requirement for airborne night operations is to enable the pilot to conduct the flight operations required by the mission and the copilot/gunner/observer to perform the mission function as well as providing navigation assistance to the pilot.

Night vision devices provide the visual contact necessary for the pilot to fly; however, other avionics will be necessary to execute required night scenarios. In addition, airborne night operations may include surveillance, target acquisition, and fire-control capabilities to meet other aircraft mission requirements.

NIGHT VISION GOALS

The basic R&D goals for night vision equipment for Army aircraft are:

- Provide common module thermal imaging components and technical support for the acquisition of the AAH TADS/PNVS.
- Capitalize on existing technology to provide a night capability for the COBRA TOW and Scout aircraft.
- Development of an improved aviation night vision goggle to permit airmobile operations into starlight.
- Extensive flight evaluation and simulation of new sensor technology and associated avionics

to improve system performance.

- Develop a family of displays for night vision systems (pilot, observer, gunner) to maximize information transfer from sensor to operator.
- Development of new sensor technology and concepts to improve total weapons systems capability.

Attainment of these goals requires close coordination among the DARCOM R&D activities involved.

NIGHT VISION PROGRAMS

Significant advances have been made in system performance, weight, reliability, and maintainability in the past 3 years with the Army development of the Universal Far Infrared (UFIR) system modules. The concept is a general development of modules (e.g., scanner, detectors, electronics) that are common not only to airborne night vision systems but also armor, anti-aircraft, and crew-served anti-tank weapon night-vision systems. The UFIR modular approach allows per-unit-cost reductions by achieving a high production base. The impact of the modular concept on weight and cost is shown in figure AV–11. In addition to the reduced sensor costs, the performance of the modular FLIR shown in figure AV–11 is twice that of previous FLIR sensors. These modules are now being provided as GFE to the AAH TADS/PNVS contractors.

A principal non-common component is the objective lens which is designed for each application, for example, for gunner and pilot. New design techniques, optical materials, and fabrication methods are

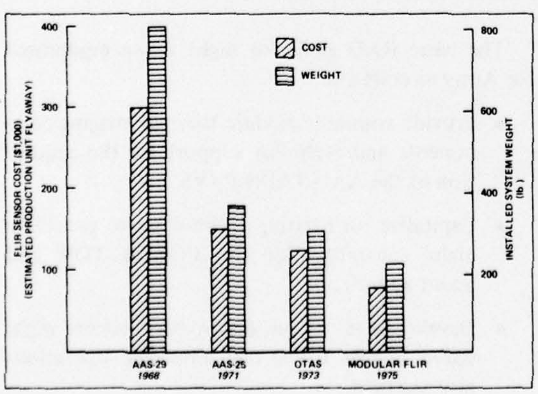


Figure AV–11. Trend of high performance sensor cost and system weight.

being investigated to reduce the present 10–20 percent portion of the sensor cost (figure AV–11) attributable to the objective lens.

During FY75 and FY76 a major Army test program was conducted by CDEC. This program, using a combination of residual and new UFIRs equipment, validated the night vision requirements for the AAH and demonstrated fire team tactics with a standoff capability outside of the threat weapons. In addition, user pilot participants demonstrated a capability for nap-of-the-earth flight at night using FLIR sensors. These systems served as the baselines for the AAH TADS and PNVS. As a result of these operational tests specific airborne systems improvements are being included for automatic hands-off-operation for the pilot and for elimination of image streaking caused by large, high contrast areas of the scene.

The AN/PVS–5, Night Vision Goggles, have been accepted as interim pilots' night vision device. They provide effective nap-of-the-earth flight assistance at light levels of a quarter-moon and above. When the probability of reduced visibility, which also limits goggles usefulness, and darkness are considered together, a considerable advantage accrues to the more expensive FLIR sensors because they are light-level independent and can penetrate the atmosphere better. This advantage in use vs sensor cost is shown in figure AV–12. The trend has been to use the FLIR sensor for those missions which cannot depend upon a rising moon. A new development program is being initiated to configure the goggles for airborne application and to introduce specific performance improvements, namely the third generation GaAs photocathode, that will enable their effective use for NOE flight in starlight. A reconfiguration of the night vision goggles for airborne use may reduce the head-borne weight from 1.9 lb to 1.5 lb. This increase in

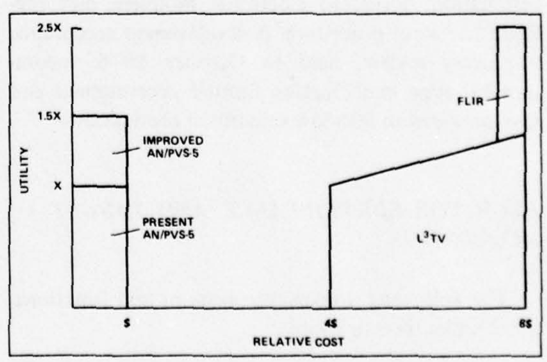


Figure AV–12. PNVS utility vs cost.

their operational utility (figure AV–12) would allow a considerable cost savings in PNVS applications as not every mission aircraft would require a sophisticated FLIR sensor. A new airborne goggle will also include a capability for faster inside/outside refocus than the present AN/PVS-5.

It was envisioned in the ROC for night vision systems for Army aircraft that a family of night systems could be sufficiently flexible to meet the limitations and requirements of future (as in the AAH) and existing aircraft. A new program, highlighting this capability, has been initiated to integrate the common modules into the sighting system and turret of the COBRA TOW. This will provide the COBRA TOW system with night capability limited by the existing turret design and, importantly, an enhanced capability in daylight in visibility ranges under 7 km as was demonstrated in tests during January–February 1976 in Grafenwohr, West Germany. An integration into a Scout aircraft has already been demonstrated at CDEC. A design for a Scout aircraft is now being planned which will have the common components and similar performance to the night sensor for the COBRA TOW. This will be an even lighter system than the OPTIC IV. With the advent of third-generation intensifier devices and improved thermal technology in the early 1980s, a new generation of airborne night vision devices is envisioned that will have significant effect on system performance (figure AV–13) in improved standoff ranges with higher probabilities of target acquisition for the postulated threat weapons and wider fields of view for NOE flight in the late 1980 time frame. Improved displays are under development for use with the second generation FLIR sensors. The displays include lighter weight, higher resolution helmet-mounted displays that can be integrated into the visor of the helmet. Each aircraft has been shown by the CDEC tests to need two independent night vision sensors. A

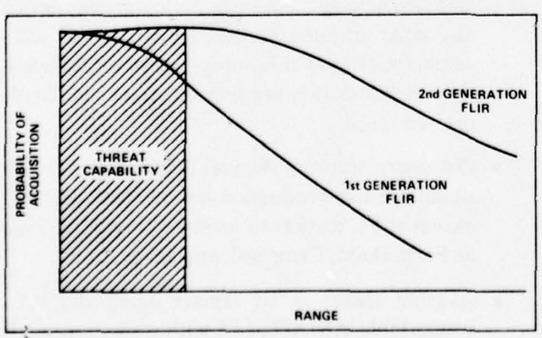


Figure AV–13. FLIR system performance.

concept of optically multiplexing the sensors together for a cost and weight savings has been shown feasible; yet necessary real-time imaging would be retained. Thus, a TADS would have the wide field of the PNVS or vice versa.

EW VULNERABILITY EVALUATION OF NIGHT VISION DEVICES AND SYSTEMS

A program to evaluate the EW vulnerability of night vision devices and systems has been initiated. The goal is to evaluate selected equipment individually and in their systems role and recommend appropriate ECCM action. This program was initiated in the third quarter FY76 and will evaluate ground as well as airborne systems.

PRIORITIES OF TECHNOLOGICAL GOALS AND OBJECTIVES

GENERAL

Items are placed in priority order in accordance with following rationale, going from highest to lowest priority:

- Immediate needs of the Army are satisfied, in order of urgency of needs, emphasizing items that have firm requirements and adequate funding.
- Next generation of items is developed, again giving priority according to need and also to amount of improvement obtainable.
- Attack barrier problems that can lead to major improvement and high payoff.
- Payoff and risk are considered throughout; that is, for equal risk, items with greater payoff would have higher priority.
- These priorities are based on the long-range objectives of this plan. Therefore, they will differ and should not be compared with other priority listings that are based on shorter term objectives, such as the RDTE 5-year program.

PRIORITIES

AVIONICS

- *AN/ASN–128 (Naviation Set, Doppler)* – To provide a lightweight self-contained navigation system.

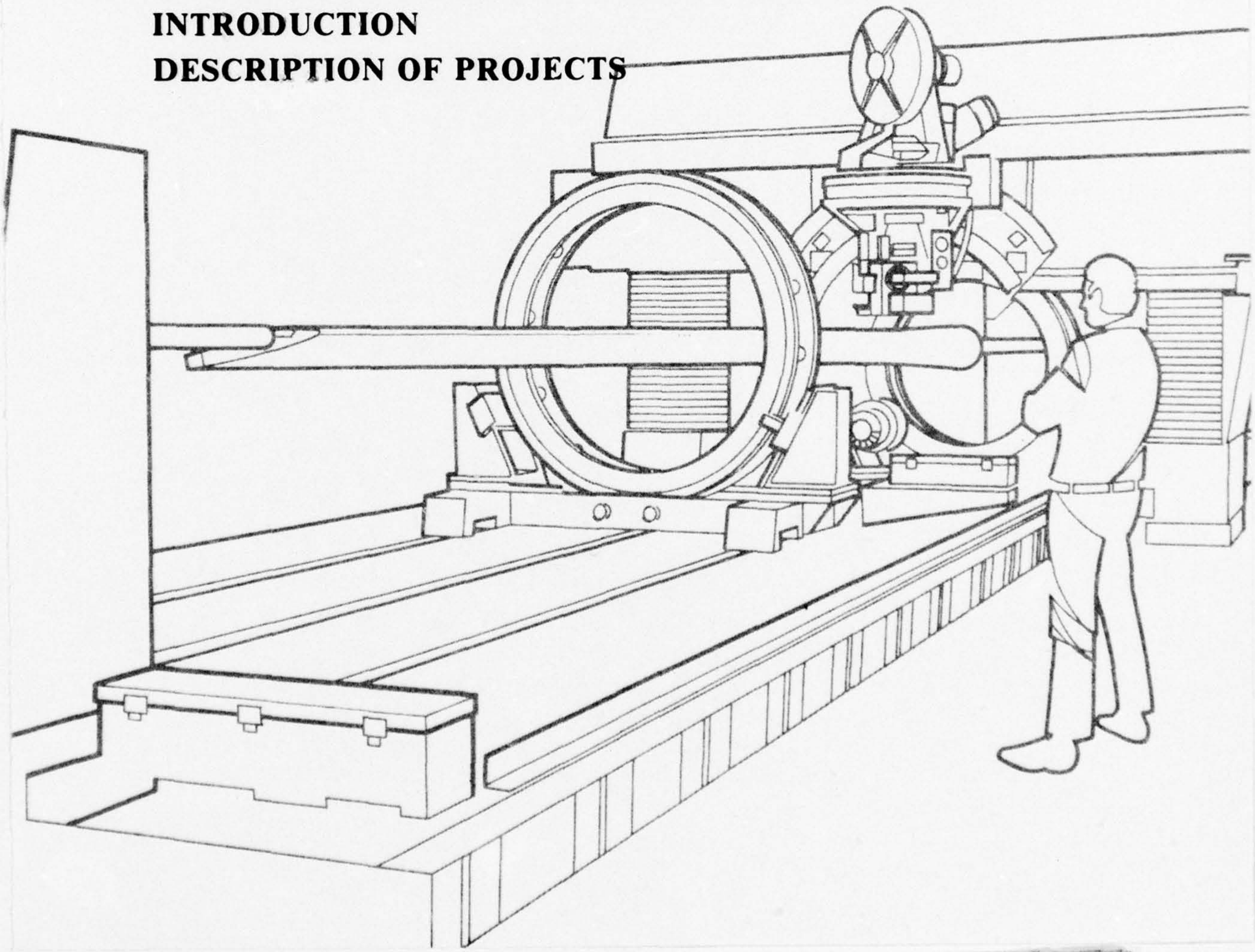
- *AN/APN–209 (Absolute Altimeter)* – To provide a standard lightweight absolute altimeter that is economical and supportable.
- *Integrated Avionics Control System* – To provide developing Army aircraft with modern integrated controls for communications, navigation, and identification equipments.
- *PLRS* – To develop an Integrated Communication, Navigation and Identification system combining both position location and data transfer functions in one system.
- *Heading Reference Product Improvement* – To improve performance of AN/ASN-43 in areas of built-in test, calibration, and accuracy.
- *Tactical Low-Level Communications* – To provide a capability for reliable and secure communications during tactical low-level flight.
- *Multifunction Environment Sensor* – To provide the aviator with the capability to detect and avoid wires and other obstacles while flying low level.
- *Tactical Hover* – To provide the aviator with the capability to perform the bob-up, hover, bob-down maneuver under tactical conditions at night in scout and attack type aircraft.
- *Satellite Navigation* – To address application of the Global Positioning System to Army needs.
- *Audio Processing, Distribution, and Isolation* – To provide new microphones, earcups, and accessory devices to improve aircraft and audio system performance under conditions of high ambient noise.
- Microwave Landing System – To provide a tactical landing system fully compatible with future US (civil and military) and international standard systems, a system designed to replace the current VHF/UHF Instrument Landing System, and a system usable in remote field sites.
- *Night Navigation/Pilotage System* – To develop an integrated system for both pilot and copilot addressing the problem of accomplishing pilotage and navigation in the night, low-level environment.
- *Digital/Modular Avionics* – To standardize digital signal interfaces among aircraft avionic systems and ground/air interfaces, and provide the basis for modular design of Army avionics equipment.
- *Air Traffic Management Visual Subsystem* – To provide terminal tactical air traffic control facilities for corps and forward/remote areas.
- *Secure/Jam-Proof Communications* – To provide the capability and provisions for totally secure airborne radio communications systems.
- *Near-Term ATMS* – Development of Very Lightweight Air Traffic Management Equipment that will allow ground personnel to determine the range and bearing from them to selected aircraft.
- *Instrumentation Technology* – Development of modular integrated control/displays and solid-state instruments for application to Army aircraft.
- *Navigation Technology* – To sustain and expand the navigation data base and exploit emerging technology.
- *Lightweight Inertial Navigation* – To reduce cost and weight for next generation inertial navigation system while retaining present system accuracy.
- *Tactical Landing Technology* – To sustain and expand the technology base required for future developments in landing guidance techniques and systems.
- *FOC/FCC* – To provide enroute air traffic control facilities in forward areas.
- *Long-Term ATMS* – Development of integrated multifunction system providing such services as precise position location, data communication, IFF, and collision avoidance.
- *Multifunction Transponder* – To exploit collision warning system, proximity warning device and radar altimiter technology to provide additional functions for homing, rendezvous, formation flights/station-keeping assistance, and landing assistance.
- *Proximity Warning Product Improvement* – To update initial production model PWD declared excess at Ft. Rucker to meet PWD requirements at Forts Hood, Campbell, and Bragg.
- *Weather Radar* – To replace aging and nonsupportable AN/APN-158 with a modern lightweight weather radar.

SURVEILLANCE AND TARGET ACQUISITION

- *Stand-Off Target Acquisition System* – To provide rapid wide-area surveillance and provide the accurate location of enemy moving targets.
- *Remotely Piloted Vehicles* – To provide precise target location for friendly weapons within range.
- *Laser Designator/Tracker System* – To enable attack aircraft to rapidly locate, with a wide-scanning tracker, targets that have been designated by ground observers using the Lightweight Laser Designator.
- *Hand-held Laser Range Finder* – To provide infantry and forward observers a lightweight portable ranging device to considerably improve the opportunity for a first round hit on selected systems.
- *Aerial Radiac System AN/ADR–6* – To provide a capability for rapid survey of radiological fallout (Priority 1).
- *Mohawk Low-Light-Level Photo System* – To provide a covert means for taking night photographs with the Mohawk OV–1D.
- *Airborne Weapons Locating System* – To locate enemy weapons in both the firing and nonfiring mode.

NIGHT VISION

- *Pilot Night Vision System* – To provide a surveillance capability at night to meet the requirements of the AAH and ASH.
- *Modular Night Vision* – To develop a sensor that will, with interchange of appropriate subassemblies, afford maximum commonality of airborne night vision equipment. The modularized concept is a high-return investment that will reduce costs associated with R&D, logistics, and support by providing standardization of equipment.
- *High-Resolution Sensors* – To develop search effectiveness equipment that will improve target acquisition. High-resolution sensors generally require moderate to small fields-of-view. Automatic detection of targets will greatly reduce operator workload and increase system effectiveness.
- *Night Vision Displays* – To develop a family of displays for night vision systems (pilot, observer, gunner) to maximize information transfer from sensor to operator. Sophisticated sensors require displays that do not limit performance yet provide maximum utility with aircraft physical restraints.
- *Design Improvements* – To develop improved design concepts to reduce current sensor weight and sophistication, while improving reliability and maintainability characteristics to enhance overall mission effectiveness.
- *Standard Configurations* – To develop standard night vision equipment configurations for use on future aircraft. Minimizing integration complexity is a means of ensuring compatibility of space, weight, and power requirements of night vision equipment with future aircraft.



INTRODUCTION

Manufacturing Technology (MT) may be broadly defined as the complex of processes, methods, and techniques available for producing items of materiel. Efforts in the MT area provide for engineering measures required to investigate, evaluate, and adapt new or technologically advanced manufacturing methods, processes, techniques, tooling, and equipment to ensure economic availability of materials, components, and systems. Efforts in MT may be undertaken during various phases of the systems acquisition process, but are commonly initiated during one of the two major phases: Engineering Development or Full-Scale Production.

Manufacturing technology efforts may coincide with certain efforts noted in other portions of this plan; for example, this occurs whenever a process for using a heretofore unused raw material is developed (e.g., casting of columbium alloys). It thus may be difficult, in some instances, to distinguish between a materials effort and a process effort. Other interfaces may occur between portions of this section and any of the various "hardware-oriented" sections such as Propulsion or Aircraft Subsystems.

AVRADCOM MT efforts, termed Manufacturing Methods and Technology (MMT) projects, are currently executed under the aegis of the Production Engineering Measures (PEM) program and are funded by Procurement Appropriations. Efforts oriented toward an end-item undertaken during the development phase and directed toward finalization of the technical data package are executed under the Producibility Engineering and Planning (PEP) program and are R&D funded.

Manufacturing problems arising from insufficiently developed state-of-the-art technology are sometimes responsible for various failures in production-buy items. Materials are often available that have characteristics for increased service life or other benefits, but the process for shaping these materials into particular forms is not sufficiently developed. A less desirable material is then substituted that results in decreased capability, reliability, or service life. Thus, MT efforts are intimately related with various product improvement efforts. The former ensures development of the process by which the materials and design specified by the latter can be used in the manufacture of an item. Figure MT–1 presents a view of MT as it relates to other programs of interest.

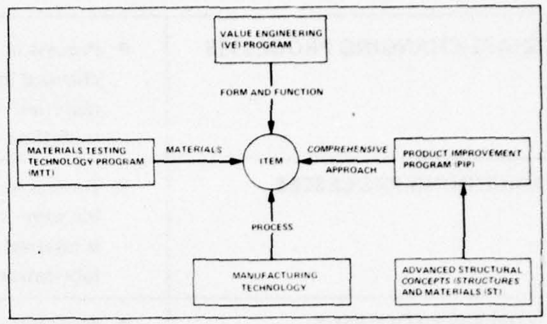


Figure MT–1. Relationship of item to certain basic programs.

The Technological Discussion subsection has been divided into the subdisciplines described in table MT–A. These divisions are logical for the purposes of this work, but are not necessarily mutually exclusive. For example, polishing is considered to be a surface-finishing process, although it could also be a machining process. In general, however, these categories are adequate to establish a structure for the different areas of manufacturing technology to be addressed.

Efforts in MT are often generic in nature and cannot readily be related to one specific aircraft system. Whenever possible, however, an attempt has been made to identify specific systems that would benefit from implementation of such technology and to translate performance requirements into MT requirements.

For a detailed explanation and description of various manufacturing techniques and processes, the reader is invited to study AMCP 706-100, "Design Guidance for Producibility."

TECHNOLOGICAL DISCUSSION

SHAPE CHANGING PROCESSES

GENERAL

Operations categorized as shape-changing processes are listed in table MT–B.

All of the processes listed are used to some extent in the manufacturing of Army aircraft. Processes such

TABLE MT–A
MANUFACTURING TECHNOLOGY SUBDISCIPLINE DESCRIPTION

SHAPE-CHANGING PROCESSES	• Process in which a raw material, either metallic or nonmetallic, is changed into its primary form for some selected part by "moving" material. Such an operation is relatively waste-free and is sometimes termed a "primary" fabrication process.
MACHINING PROCESSES	• Process in which a raw material is changed into its primary form for some selected part by removal of material. Such an operation is relatively wasteful and is normally termed a "secondary" fabrication process.
JOINING PROCESSES	• Processes wherein two or more pieces of material are joined by fasteners (mechanical joining), by creating metallurgical changes in one or more of the materials (metallurgical joining) or by the application of a chemical agent that creates a bond through use of a chemical interaction (chemical joining).
SURFACE FINISHING PROCESSES	• Processes used to ensure a smooth surface, achieve great dimensional accuracy, obtain aesthetic appearance or impart a protective coating.
ALTERATION OF PHYSICAL PROPERTIES PROCESSES	• Processes that change the physical properties of a material by application of an elevated temperature or by repeated stressing of the material.
COMPUTER-AIDED MANUFACTURING PROCESSES	• Processes wherein programmed numerical values, stored in some form of input medium, are automatically read and decoded to cause a corresponding movement of the machine that it is controlling.

TABLE MT–B
SHAPE-CHANGING PROCESSES

Casting	Piercing	Electrohydraulic Forming	Compression Molding
Forging	Swaging	Magnetic Forming	Transfer Moulding
Extruding	Bending	Electroforming	Injection Moulding
Rolling	Spinning	Powder Metal Forming	Callendering
Drawing	Stretch Forming	Roll Forming	Lamination
Squeezing	Torch Cutting	Shearing	Vacuum Forming
Crushing	Explosive Forming	Compounding and Preforming	

as squeezing, crushing, piercing, bending, roll forming, shearing, and torch cutting are well understood and sufficiently developed processes; they present no special problems and have not been included in future development plans.

The primary processes that, with further development effort, will effectively support future Army aviation systems are listed in table MT–C.

TABLE MT–C
PRIMARY DEVELOPMENT PROCESSES

METALLIC	NONMETALLIC
Casting	Casting
Forging	Compression Moulding
Extruding	
Explosive Forming	
Powder Metal Forming	

CASTING

General. All casting processes are basically similar in that the metal being formed is in a liquid or highly viscous state and is poured or injected into a cavity of the desired shape. Types of castings of special interest to Army aviation include die casting, investment casting, permanent mold casting, and precision casting.

Technological Voids. Turbine engine rotors for the compressor and power sections present the area of greatest possible gain in advanced castings. It has been shown that casting is a most economical method of manufacturing advanced turbine parts for both small and large airflow systems. Particular emphasis is required for the following developmental areas:

- Casting of high-temperature materials, capable of withstanding turbine inlet temperatures in excess of 2500° F as compared to the current 1800–2000° F.
- Casting of thin-walled blades, 0.010–0.015 in. thick, are required for small-turbine engine design.
- Development of casting techniques for titanium alloy components.
- Development of bicasting technique for radial turbine rotors with repeatability of material properties and minimum of 5000 hr of service life while operating in a gas turbine engine/gas generator environment.

Technological Discussion. Turbine inlet temperature increase from 1800° F to 2700° F for a 10:1 compressor pressure ratio would result in a decrease in specific fuel consumption while increasing the specific horsepower (hp/lb air/sec) from 125 to 210. This is a significant factor, which makes the development of high temperature castings imperative. Columbium metal, with a melting point of 4500° F, and its alloys are uniquely suited in this respect. Under previous AVRADCOM-sponsored research, the technology for precision casting (T55 engine first-stage nozzle vane) of columbium base alloys (e.g., SU-3) has been greatly improved, but further work is needed to understand the effects of operating variables on casting quality of these reactive metals. Of more immediate consequence is the casting of high temperature alloys in the directionally solidified condition to yield a product which exhibits increased thin-wall creep rupture and low cycle fatigue capability. Benefits would be realized in the production of turbine blades with the ability to operate at higher temperatures and/or with decreased cooling air requirements.

State-of-the-art, thin-wall castings do not meet high-temperature property requirements, and high-temperature mechanical properties decrease as blade thickness decreases. Of particular interest is the casting of small turbine blades with cooling passages.

Prior work has shown that some commercially available titanium alloys can be cast. Other alloys have been developed specifically for casting. Since compressor design requires high strength-to-weight and stiffness-to-weight materials for static components exposed to a temperature range of 100–800° F, certain titanium alloys have been used. Recent advances in titanium casting technology make it possible to use titanium castings for rotating components as well as static components. Manufacturing studies indicate that cost savings of up to 50% can be achieved through precision casting titanium in lieu of forging and machining centrifugal compressor components. However, further development is required to produce thin sections and complex shapes with structural integrity.

The technique of bicasting offers several advantages to the Army as a potential user of radial turbine rotors. Currently, cooled axial turbine components represent approximately 40 percent of the cost of a gas turbine engine. With the development of improved bicasting processes, the high rejection rate of present casting techniques should be reduced significantly, representing a significant life-cycle cost reduction. In addition, the radial rotor will replace two stages of the axial turbine with a single stage at reduced cost and weight.

Application. Programs aimed at developing cost effective manufacturing methods for casting high temperature alloy turbine blades must be undertaken so that benefits may be realized in the advanced technology engines under development for future airmobile systems.

A current program is aimed at developing the manufacturing technology for fabricating small, cooled, axial turbine engine blades. The primary effort is aimed at refining blade casting techniques and processes developed during the advanced development program for the UTTAS engine. A pilot production fabrication process is being established and

improved to the point that the rejection rate is less than 2 percent, while maintaining quality required for long-life engines. Special tooling and casting accessories will be developed in support of the end-item; a technical data package and manufacturing specifications will then be developed. Future work will include development of inspection techniques for cooled, axial, cast turbine blades. When work is completed, the process will have advanced from a limited fabrication operation to a full production capability.

Efforts to develop advanced titanium casting techniques will be applied to components of the auxiliary power units and the engine for the AAH and UTTAS. The centrifugal compressor impeller on the APU is presently manufactured by extensive machining of a rough forging – a costly and wasteful operation. A program to refine casting techniques and apply them to casting the impeller will result in cost savings estimated at an average of $1,000 per unit. The compressor casing on the T-700 engine is also machined from a forging at the present time. A program aimed at developing centrifugal casting techniques will result in estimated cost savings of $650 for each case.

FORGING

General. Forging consists of working metals into a desired configuration under impact or pressure loading. It allows for a refined grain structure with corresponding improvement in mechanical properties. "Precision forging" denotes a variation on the conventional process; its use often helps eliminate or minimize machining operations. In precision forging, the dimensional tolerances, surface finish, and surface metallurgical quality are equivalent to those produced by standard production machine tools. Forging is classified into such categories as closed die, open die, conventional die, precision die, and upset forging.

Technological Voids. The use of forgings in aircraft design has increased considerably as forging technology has advanced, but it still represents a small percentage of the potential application. Additional and/or continuing developmental efforts are required in the following areas:

- Isothermal forging process die capability limits and prediction of optimal combinations of temperature, pressure, and lubrication.
- Isothermal roll-forging of compressor blades.
- Higher strength with improved mechanical properties, especially superior fatigue and fracture toughness for titanium forgings.
- Elimination of forging flash and excessive machining after forging.

Technological Discussion. The isothermal forging process permits the shaping of intricate parts from difficult-to-forge materials such as titanium and high-strength steels. Die chilling is eliminated as increased plasticity of forging materials at high temperatures is maintained by keeping the dies themselves near forging temperature. Further research is needed on deformation rate, forging temperature, die pressure, and lubrication types and requirements.

Isothermal roll forging of compressor blades also holds a great deal of promise for Army aviation. Preliminary effort has indicated that reduction of the maximum section of titanium blades approaches 80 percent (Ti-6Al-4V). Such a process would yield precision, as forged contours with a fine (16 rms) finish and clean, uncontaminated surface on the processed blade, eliminating the requirement for atmospheric protection in processing and cleanup. Figure MT–2 presents an overall comparison of conventional hot forging of titanium with the isothermal roll forging process. Figure MT–3 presents this comparison for the number of reduction passes required.

Optimized thermomechanical processing effectively produces titanium forgings with superior fatigue and fracture toughness properties. Now it is necessary to produce large titanium forgings to specific processing specifications and verify mechanical

HOT FORGING	ISOTHERMAL ROLL-FORGING
MATERIAL	
SCALING IN PREHEAT	NO SCALING
METAL FLOW	
LIMITED BY DIE CHILL LIMITED BY HIGH FORGING RATE	DIE HEATED WITH STOCK SLOW FORGING RATE
DIE LIFE	
STEEL LOW THERMAL FATIGUE HIGH IMPACT FORCE DIE WASH (Fe-Ti REACTION) WEAK ABOVE 1200 F	Mo EXCELLENT THERMAL FATIGUE LOW FORGING PRESSURE NO REACTION WITH Ti STRENGTH RETAINED TO 2000 F
CONTAMINATION OF FORGING	
3 TO 5 MIL DEEP	NEGLIGIBLE
SURFACE CONDITION	
>100 RMS LOW PRECISION	16 RMS HIGH PRECISION

Figure MT–2. Comparison between isothermal roll forging and conventional hot forging.

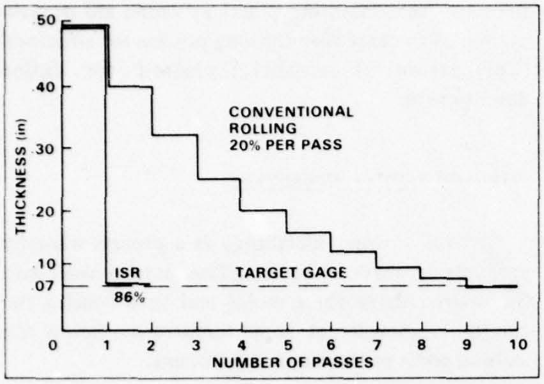


Figure MT-3. Comparison between isothermal rolling and conventional rolling; number of passes required to achieve a given reduction.

properties as a function of full-scale production forging and heat-treating variables. Both production processing specifications and base design allowable properties for components fabricated in accordance with the specifications should be formulated.

A large portion of the material in a forging is wasted in flash and machining following conventional forging. A highly developed precision forging process would allow for elimination of a majority of this flash, and proper material placement (die design) would eliminate excessive machining. The advent of this process for a particular item, such as a rotorcraft transmission component, would first require the development of new and sophisticated methods of billet preparation, die design, and billet heating. Using a selected number of components as candidates, it would be necessary to successively develop an overall process design with: (1) billet weight and material placement control, (2) determination of tooling materials, (3) detailed design and manufacturing method, and (4) optimal forging temperatures and pressures to eliminate oxidation and scaling.

Application. Full exploitation of isothermal forging of the centrifugal compressor impeller and incorporation of this forging process into impeller fabrication could reduce the associated cost of processing by a minimum of 15 percent. A feasibility forging program that will facilitate die design for the forged impeller fabrication has been completed, but further work as noted above is required. After all areas relating to the process are sufficiently understood, tooling for the impeller itself must be developed; the actual finished component will then be produced and subsequently qualified through a qualification testing program. Further research on deformation rate, forging temperature, and die pressure is required so that future systems may make use of higher-strength, forged materials possessing more desirable mechanical properties.

An isothermal roll-forging effort currently under way includes fabrication of hard tooling for blades, design and fabrication of the production machine, and subsequent work in fine grain and beta forging, followed by metallurgical and mechanical testing of the actual finished components. This technology will be available for production of compressor blades by 1980, making it available for near-term future airmobile systems.

The development of titanium forgings with superior fatigue and fracture toughness would greatly benefit all future airmobile systems, primarily in the rotor hub components.

AVRADCOM-sponsored research has established the manufacturing process for precision forged spiral bevel gears. Further testing of produced gearing, followed by dissemination of results to industry, should aid in implementation of the process. It is imperative that the additional effort be made now to reap the benefits of previous research.

EXTRUDING

General. The extrusion process is characterized by the forcing of metal, normally confined to a pressure chamber, through specially formed dies. In the process of cut extrusion, a heated billet is placed in a die chamber and a block and ram placed in position. The metal is then forced through the die opening. Impact extrusion, usually done with a relatively cool metal slug, can be subdivided into two major categories: forward and reverse. Forward extrusion is quite similar to cut extrusion, with metal flowing forward through an opening in the die. In reverse extrusion, the slug placed in the die is also struck with the punch, but the metal flows up and around the punch rather than forward through the die. Cut extrusion is used primarily in aviation manufacturing.

Technological Discussion. Development of the process of isothermal extrusion, wherein a nearly constant die exit temperature is maintained, will provide an effective, highly repeatable manufacturing process for fabricating aluminum and titanium structural

parts. During the process, heat is generated by friction and deformation, and heat is lost to the tooling. For a given material and reduction, extrusion speed must be varied to control the exit temperature. At present, a significant amount of process development has been completed in this area, and computer programs simulating the extrusion process by calculating heat generation, heat transport, and heat transfer for given extrusion conditions have been formulated. To ensure the capability of obtaining close tolerances, forming intricate shapes, and obtaining a consistent grain structure, additional work must be performed. Further studies of exit temperature in extrusion as a function of reduction, material, ram speed, and shape of extruded product must be made. Following this, speed adjustments or variations in reduction can be determined that will ensure isothermal extrusion conditions.

Applications. The isothermal extrusion process, if further development effort is applied in the near future, should be sufficiently sophisticated for availability and use by mid-FY80.

EXPLOSIVE FORMING

General. Explosive forming has been used widely for producing parts from sheet metal. Materials are generally formed with explosives in annealed condition at ambient temperature. Water is normally used as a pressure transfer medium. Acting as a ram, the water transmits pressure to the metal causing it to flow against the die contour.

Technological Discussion. Long die fabrication times and high associated costs have prevented full realization of the manufacturing potential of the explosive forming process; such a forming method is ideally suited to meet the precision sheet metal forming needs of the airframe industry. At present, limited production runs do not justify the high cost of all-metal tooling. Thus, many airframe components are composed of multipart builtup structures requiring large amounts of fabrication and assembly time. Die systems for high energy rate forming have been constructed of a variety of materials, including ice, steel, concrete, and fiberglass. Further work must be done in fabricating and evaluating such "low cost" dies, with special emphasis on components.

Application. A program consisting of materials selection and evaluation, prototype die fabrication, full-scale die fabrication, and preparation of guidelines for manufacturing practices would aid in making use of the explosive forming process for structural fabrication of aircraft planned for future development.

POWDER METAL FORMING

General. Powder metallurgy is a process whereby products are made by pressing fine metal powder into the desired shape (in a mold) and then heating the compacted powder at some temperature below the melting point of the major constituent.

Technological Discussion. Trends in powder metallurgy indicate that turbine wheels for advanced engines are good candidates for application of this technology. Such wheels require exceptional tensile strength, stress-rupture strength, hot corrosion resistance, and thermal fatigue resistance. Available material does not offer an adequate combination of the required properties. The powder metallurgy approach allows for cast alloy composition, providing inherent stress-rupture strength; for wrought processing, providing tensile strength; and for limited restriction on chemical composition, providing increased hot corrosion resistance, Figures MT–4 and MT–5 illustrate some of these characteristics in comparison with conventional forging of bar stock. Further work must be done in determining the value of parameters related to the powder, forging, hot pressing, and heat treatment.

Application. A current program has demonstrated that hot isostatic pressing is a cost-effective method for fabricating turbine disks from high-hardness

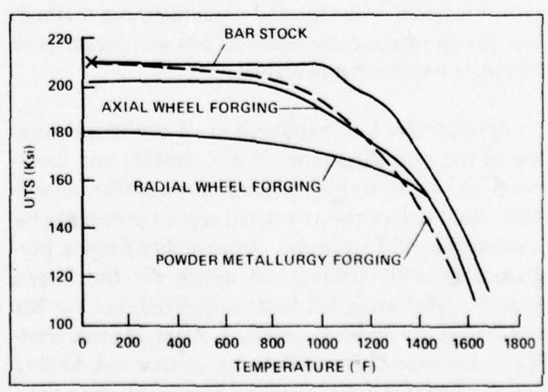


Figure MT–4. Comparison of powder metallurgy forging and bar stock forging; tensile properties.

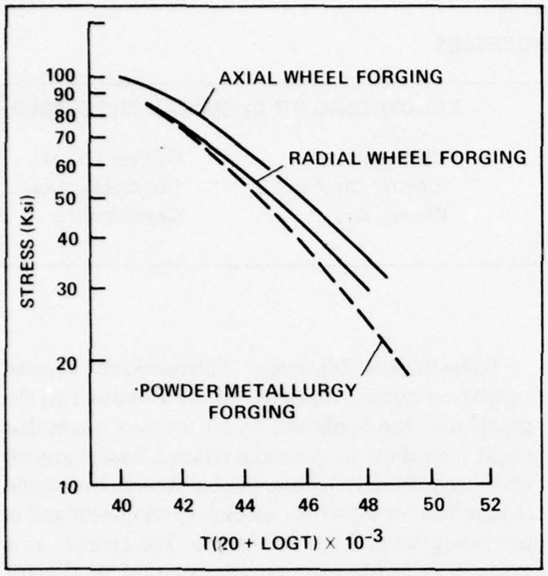


Figure MT–5. Comparison of powder metallurgy forging and bar stock forging: stress-rupture properties.

Rene 95 material. Powder metallurgy forging processes for the axial turbine disks are being updated and improved for production quantity utilization. The program was aimed primarily at development of the T700 engine for UTTAS and AAH.

COMPRESSION MOLDING

General. In compression molding, material is placed into a metallic mold; as the mold closes, the pressure causes the softened material to flow and conform to the shape of the mold. Compression molding is useful in forming plastics from either the powdered or solid tablet states.

Technological Discussion. A major factor in the cost of molded composite structures is the cost of tooling involved. The number of pieces produced is seldom enough to warrant the use of matching metal dies, since the cost of the dies is reflected in the cost of the part. Tooling costs can be reduced by 50 percent or more by using a low-cost die material in high energy rate forming (HERF) of metal parts. This die system can be prepared quicker than conventional matched metal molds; the dies themselves would possess a hard nickel surface backed up by a reinforced concrete-like material. The nature of such dies allows for the introduction of heating and cooling coils near their mating surfaces; this feature permits uniform heating and cooling of the die face and eliminates the need to heat the whole die, a costly and time consuming operation.

A solution to the problem of low stiffness in transmission gearbox housings can be realized by compression molding these housings. In this case, high modulus, unidirectional, continuous filament graphite epoxy would be used. A determination of manufacturing procedures and techniques, coupled with optimization of a gearbox housing design and the fabrication of production-tooling, dies, and molds, must be completed prior to fabrication of prototype housing. Simulated static and dynamic test results of prototype housings must be compared to existing magnesium housing test results to establish acceptability.

Application. A recent program utilizing low-cost, integrally treated dies for fabricating Kevlar fairings has established the feasibility and low-cost benefits of this process and demonstrated its applicability to systems now under development, such as UTTAS and AAH.

Development of filament graphite-epoxy compression molding techniques could be completed in time for systems entering engineering development by FY80.

MACHINING PROCESSES

GENERAL

Processes classified as machining operations are included in table MT–D.

Although chip removal processes are widely used throughout the aircraft industry, primarily because the base material properties normally remain unchanged, such processes are extremely wasteful. Consequently, few efforts aimed at refining chip removal processes are being undertaken. Rather, efforts to do away with extensive machining are of more interest to Army aviation. Where a unique application exists or where no other type of process is acceptable, machining processes are undergoing further development. Such is the case with ultrasonic machining, electric discharge machining (EDM) and electrochemical machining (ECM).

TABLE MT–D
MACHINING PROCESSES

MECHANICAL CHIP REMOVAL PROCESSES			ELECTRONIC OR CHEMICAL PROCESSES	
Turning	Planing	Shaping	Ultrasonic	Optical Lasers
Drilling	Boring	Reaming	Electric Discharge	Electrochemical
Sawing	Broaching	Milling	Electro Arc	Chem-Milling
Grinding	Hobbing	Routing		

ULTRASONIC MACHINING

General. In ultrasonic machining, sonic energy is applied to a tool performing work on a block of raw material. Many ultrasonic machining operatins have advanced little beyond the experimental stage; in most cases, necessary baseline data are minimal, if available at all. Figure MT–6 presents a brief review of the current status of some processes. There are several potential areas for ultrasonic energy application in Army aircraft manufacturing, as determined from a recent AVRADCOM study. Some of the processes requiring additional development are discussed below.

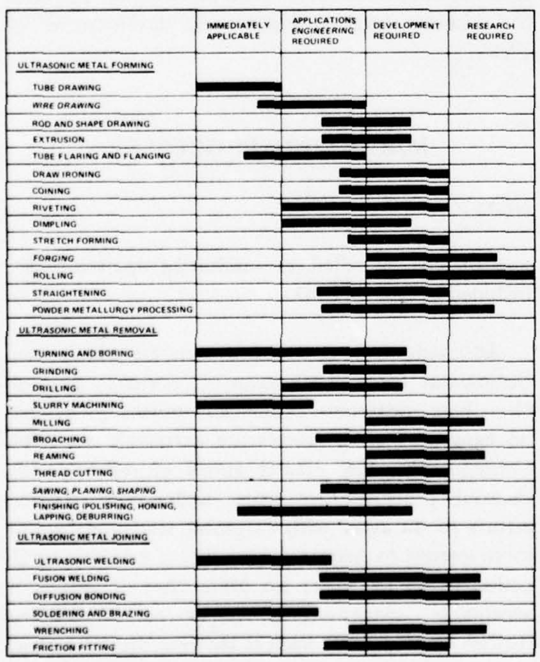


Figure MT–6. Ultrasonic processes.

Technological Discussion. Ultrasonically assisted turning on outside diameters offers a solution to the problem of hand-polishing to remove tool marks that might contribute to structural failures. Such a process would significantly reduce this handwork, but would require further effort in machine development and in processing some items for testing. The process, as it exists, is primarily a laboratory operation. Work must be undertaken to bring it up to full-scale production process. Baseline data and quality assurance criteria must be developed to ensure that the process produces usable results for the Army.

Rotary ultrasonic machining, wherein both rotational and axial vibration are imparted to a tool, has proven effective on processing such material as high-alumina ceramics, technical ceramics, ferrites, porcelain, glass, boron-tungsten laminates, and beryllium. Operations performed on these materials, using the rotary ultrasonic concept, include drilling, milling, grinding, threading, and specialized lathe operations. Figure MT-7 presents a typical comparison of ultrasonic and nonultrasonic drilling (the work piece is 1/15-inch titanium). However, while many superhard materials can be effectively machined with the rotary ultrasonic principle, others cannot be. Machining of

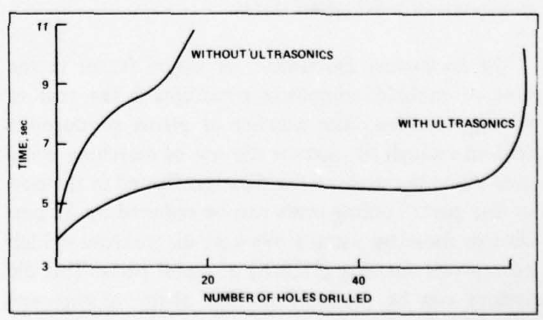


Figure MT–7. Comparison between ultrasonic and conventional drilling.

boron carbide remains largely a laboratory phenomenon, primarily due to the fact that its hardness approaches that of the diamond tool itself. Much work must be done in examining the bonding agent that secures a diamond tool to its holder, since the agent currently holds the diamond so tightly that worn diamond is not expelled from the work area; cutting edges thus become cluttered and wear down. In addition, effort must be expended in the drilling of extremely small holes (0.04-inch diameter) before such an operation becomes practical for full-scale production.

Application. A current program aimed at scaling up the ultrasonically assisted turning operation will allow application of this process to the full-scale production of systems as imminent as UTTAS and AAH.

Work must be undertaken to establish manufacturing parameters for other ultrasonic machining processes for application to developmental systems, such as ASH.

ELECTRICAL DISCHARGE MACHINING

General. In electrical discharge machining metal is removed by rapid spark discharge between a negative electrode, the tool, and a positive conductive workpiece, separated by approximately 0.001 in. of dielectric fluid. The workpiece material is cut away by the spark discharge, and dielectric coolant washes away the particles of eroded metal. The EDM process was developed for machining carbides, hard nonferrous alloys, and other hard-to-machine materials.

Technological Discussion. State-of-the-art technology for ceramic machining does not permit economical processing of intricate, large shapes. The current method entails "hogging" the pieces from a single billet by conventional machining; such an operation is quite costly and time consuming on a ceramic as hard as silicon carbide. Use of EDM would greatly reduce machining time and in addition would reduce tooling costs, as the diamond tooling normally required in the conventional process would not be required. Also, EDM is an extremely attractive method for machining complex shapes such as turbine components. Further effort is required in investigating the effect of varying process parameters (e.g., tool material, size, and shape; feed rate; dielectric fluid) on properties of the as-machined component. Comparisons between its conventional counterpart, based on an evaluation of the physical properties and parameters of each, must be made. Surface characterization by optical and scanning electron microscopic techniques must be conducted and attempts made to establish a correlation between surface finish and strength properties.

Application. The use of EDM for machining ceramics should be ready for application to aircraft components in the 1980s.

ELECTROCHEMICAL MACHINING

General. In electrochemical machining, the raw material to be machined functions as an anode while the tool functions as a cathode. A current is passed through a flowing film of conductive solution separating workpiece from tool. In effect, ECM is a deplating operation wherein metal is removed from the workpiece by electrochemical decomposition. Typical applications of ECM to aircraft include use in making turbine and compressor wheel blades, drilling engine cooling holes, face turning of discs, and performing various other operations on high-temperature alloy forgings and high-strength, high-hardness materials.

Technological Discussions. Current conventional machining methods for centrifugal/radial compressor wheels is time consuming, necessitates multiple setups, and consumes tooling at a rapid rate. Newer superalloys and titanium alloys developed for their high strength capabilities are receiving increased attention for use as compressor wheel materials. Unfortunately, the improved materials are not efficiently machined by conventional techniques. Further required effort includes the establishment of initial tooling and ECM process parameters, fabrication of tooling and machining of test items from conventional materials, subsequent machining of test pieces from titanium alloy, and testing, inspection, and comparison of these items.

Application. Further development of the ECM process could benefit systems entering engineering development after 1980.

JOINING PROCESSES

GENERAL

The joining processes can be categorized into three main areas:

- Mechanical joining.
- Metallurgical joining.
- Chemical joining.

Mechanical joining processes will not be addressed in this section, since they are actually an "assembly" operation rather than a process, in that the means for fastening together a number of parts is totally mechanical.

METALLURGICAL JOINING

General. Several metallurgical joining processes are of interest to the Army; among these are welding, soldering, brazing, and solid-state bonding. Of primary future interest to Army aviation are processes of welding and solid-state bonding.

Technological Discussion. The present method of manufacturing a titanium rotor blade spar consists of extruding the part and fully machining it all over. The finished machined spar weighs only about 10 percent of the starting extrusion. Because the cost of titanium is high and because this process involves a considerable amount of scrap and machining, this method is too costly for production incorporation of titanium spars. A titanium main rotor blade spar produced by cold brake forming a Ti–6Al–4V sheet and welding or diffusion-bonding the seam would bring about estimated cost savings of at least $2,600 per spar. The seam on such a spar requires a long, narrow, smooth configuration free of joint mismatch, undercut, and porosity. Present joining systems are marginal in capability and must be scaled up to make required high-quality bonds on a routine production basis.

The increased performance characteristics being specified for advanced helicopter designs will require a proportionate increase in the size of many of the major helicopter components. Of particular significance are those components where large size, high strength, and minimum weight are prime considerations (e.g., motor mounting, landing structures, hold-down tabs, spars for blades, and panel stiffeners). Current press capacities would be exceeded in forging many of the new components needed for advanced helicopters, and the limited use would not justify the cost of building larger presses. Effort may be directed toward providing specifications and description of manufacture for prototype assemblies that will be made from combining smaller structural elements to form larger components through the use of precision joining techniques such as solid-state bonding and diffusion bonding. Delineation of the pertinent manufacturing process parameters for conventional hub assemblies and examination of requirements for conversion to welded assemblies must be accomplished.

Application. Because titanium tubes for certain blade spar configurations will require joints in tapered wall thickness and/or varying spar diameters which cannot be adequately accommodated by present day fabricating systems, it is necessary to scale up equipment for tube joining. Results of this effort would be immediately applicable to UTTAS.

The joining of high strength-to-weight ratio materials such as titanium alloys has been proven to be a technically feasible fabrication process, but a need exists to develop the manufacturing method and application. Results of such an effort would be particularly applicable to systems fulfilling mobility mission requirements.

CHEMICAL JOINING

General. Chemical joining, as previously noted, is defined as the holding together of two or more parts by the application of a chemical agent between the parts that, by means of a chemical interaction, creates a bond. Adhesives are substances normally used to hold such parts together; types of adhesives include natural, thermoplastic, thermosetting, and elastomeric. Of primary interest here are thermosetting adhesives. The joints formed are stronger than the other adhesive types and heat resistance is exceptional (up to 500° F).

Technological Discussion. In many manufactured components, the effect of bond-line variations on service capabilities is virtually unknown. As a consequence, manufacturing tolerances on adhesive bond-line are often determined on the basis of the most refined production technique. It appears that establishing accurate tolerance criteria would lead to a possible choice of a more economical manufacturing technology. Tolerance requirements must be established for typical strips, sheets, and cylindrical configurations using commercial nylon-epoxide adhesives as

well as advanced high-temperature systems. On the basis of unusual assembly procedures, a series of joint tests must be performed wherein adhesive line geometry will be systematically varied with the range of ordinary dimensional control. Subsequently, fatigue experiments should be conducted for temperatures varying from −67° to 350° F.

Application. Data would then be available on tolerance requirements for important classes of structural materials and adhesives. Application of results would be primarily limited to airframe attachments and joints on near-term future airmobile systems.

SURFACE FINISHING PROCESSES

GENERAL

Table MT–E lists surface-finishing processes. Of particular interest to developers of manufacturing processes are inorganic coatings, grinding, and electroplating.

TABLE MT–E
SURFACE-FINISHING PROCESSES

Polishing	**Metal Spraying**
Abrasive Belt Grinding	**Superfinishing**
Barrel Tumbling	**Inorganic Coatings**
Honing	**Anodizing**
Lapping	**Parkerizing**

INORGANIC COATINGS

General. Many inorganic coatings have been developed for a wide variety of uses, but present coatings are insufficient to solve many of the problems associated with Army rotorcraft systems. To this end, new coating materials, methods, and processes are being developed. The four basic methods used to impart coatings to material are:

- Metallurgical
- Electrochemical
- Chemical
- Mechanical

Technological Discussion. Because of their high strength-to-weight ratio, titanium alloys have been considered for use in transmission gears, but such applications depend on the development of compatible alloy/coating systems to overcome wear and galling problems. Several promising coatings for titanium alloys have been developed on a laboratory scale but have not been applied in a production environment to gear profiles and thick-section parts with extremely close tolerances. Previous R&D includes investigation of the effects of temperature on the coating structure and thickness, and an examination of coating adhesion, wear resistance, and mechanical properties of the base materials. Diffusion treatments for electroless nickel coatings plus chromium, at temperatures in the 850°–1350° F range, have resulted in marked improvement in adhesion and wear resistance with little or no degradation in mechanical properties. Wear-testing under identical conditions indicates that the diffusion-bonded coating on titanium is superior to case-hardened steel. Coating processes must be scaled up and modified to accommodate large gears and roller test specimens.

Titanium alloys cannot withstand the erosive, corrosive environment to which they would be exposed in the compressor section of gas turbine engines. Protective coatings of titanium diboride and titanium carbonitride have been developed and evaluated in the laboratory. Manufacturing methods must be further developed to minimize coating variations over close tolerance component profiles. The extent of these variations and the effect of the coating on the mechanical properties of the component material must be determined. Production techniques for coating engine components are still to be developed and coated components tested.

Application. Programs to establish manufacturing methods for applying coatings must be undertaken in order for titanium to become acceptable for specialized application in future airmobile systems.

ELECTROPLATING

General. The process of electroplating consists of passing an electric current from an anode to a cathode (this being the object on which metal is deposited) through a suitable electrolytic solution in the presence of a catalyst. Electroplated coatings provide wear resistance, corrosion resistance, hardness, and reflectance. The process is relatively inexpensive and can be applied to many different shapes and sizes, although it is somewhat difficult to achieve plating on contours, grooves, fins, ribs, recesses, and angled edges.

Technological Discussion. Much effort is being expended in investigating various coatings for helicopter transmission gears. An AVRADCOM-sponsored investigation has indicated that honing of gears can increase resistance to scuffing by 25 percent (at 10 rms) over current gears using AISI-9310 material. However, it has been determined that electroplated coating of current gearing can provide even greater resistance to scuffing; silver plating has increased scuff resistance by 75 percent over current transmission gears. Preliminary tests have shown that the surface finish of the gear had also increased from the normal 12 rms to 5 rms. In addition, it has been shown that VASCO–X2 material provides increased load-carrying capability and scuff resistance.

Application. Further work remains to be done in actually implementing the process of silver electroplating. Quality assurance provisions and a technical data package must be written; however, the basic manufacturing concept has been examined and recently proven sound. Benefits of this effort will accrue to that generation of Army aircraft now under development, including UTTAS and AAH.

GRINDING

General. In machine shop practice, grinding refers to the removal of metal by means of a rotating abrasive wheel. Very little pressure is normally required, and work can be finished to very accurate dimensions within a short time.

Technological Discussion. The hydrostatic grinding process, wherein a conventional gear grinder is equipped with hydrostatic air spindle and hydrostatic ways for improved grinding capability, can yield spur and helical gears having approximately 2.2 times the load capacity of conventionally ground gears of 10 rms surface finish. Surface finishes of 1.0 rms have been obtained with total topographic variations across the gear tooth of less than 0.000025 in. and local variations of less than 0.000005 in. The hydrostatic grinding process will be applied to other types of gearing in the future.

Application. A final report on the work has been completed; the process of hydrostatic grinding for aircraft-quality gearing appears ready for mass production, although additional checkout and flight testing of associated gearing must be accomplished.

COMPUTER-AIDED MANUFACTURING

GENERAL

Computer-aided manufacturing (CAM) is an ever-widening field in terms of manufacturing operations capable of being performed in conjunction with a computer. Although operations currently performed by CAM could be classified under their more conventional headings (e.g., milling, forging) it is felt that the area of computer-assisted manufacturing operations deserves special attention as an entity in itself.

HELICOPTER GEARING

A promising application of CAM lies in the design and production of helicopter gearing. Conventional gears are overdesigned to allow for deficiencies in tool design and fabrication. If gears and gear tooling were designed simultaneously using the aid of a graphic interactive device such as the IBM 2250 CRT, a large amount of this overdesign would be eliminated and a more accurate tooth profile configuration would result. In addition, a numerical control tape could be generated by the computer after the gears and tooling were designed. By running the tape through a suitable postprocessor, a series of instructions to a machine tool would be generated, again in tape format. The tooling can then be generated followed by use of that tooling in the actual gear cutting process. Thus, much of the conventional gear design and manufacturing process could be automated. It is estimated that overall prototype production leadtime would be reduced from 18 months to approximately 8 months. It is also anticipated that the optimized gear design may provide an increase of 25 percent in gear durability, thus significantly decreasing acquisition and support costs. Such effort would support systems entering engineering development after 1980.

COMPOSITE STRUCTURE

The use of filament winding in fabricating advanced composite structures should also be increased within the next 20 years. AVRADCOM-sponsored effort is developing improved techniques and equipment to automate the fabrication of Tetra-Core, a fiber-reinforced composite core material. The primary applications of Tetra-Core lie in the replacement of existing aluminum honeycomb structures and the use of actual structural elements. Work still to be performed includes investigation of both filament winding and complex weaving techniques to

determine the optimum technique to fabricate Tetra-Core efficiently. Following this, the design and development of equipment, tooling, fixtures, and adapters required to prove out the fabrication approach must be conducted. Fabrication of prototype production equipment capable of producing Tetra-Core with combined/controlled variables of core thickness, width, length, cell dimension, and fiber/matrix ratio must then be accomplished. The process itself will be sufficiently developed for use in production by 1979.

A six-axis, tape layup machine is being developed under AVRADCOM sponsorship for use in the automated manufacture and monofilament fiber composite structures. Currently, the benefits available from use of composite materials in helicopter rotor blades cannot be realized on mass production basis; composite blades are hand-wrapped, an expensive and time consuming process. The tape layup machine under development will provide an automated method for fabricating these complexly contoured blades. Special features of the equipment to be developed include layup capabilities at 100–300 in./min, capability for closely controlled cross-sectional area, and ability to maintain tight tolerances on tape alignment. The current effort is in the machine fabrication phase; design and planning have been completed. Results of the effort should be completed in time for use on such systems as ASH.

COMPUTER-AIDED DESIGN/MANUFACTURING

AVRADCOM is sponsoring work to establish a method for computer-aided design (CAD) and computer-aided manufacturing of extrusions. The primary use of CAD is in preforming and finishing dies, while CAM will be applied mainly to the manufacture of dies. The computerized method of actually designing the process and the dies to be used in that process is being developed for use in an interactive mode. A cathode ray tube terminal, connected to a CDC 6400 computer, is being used in designing the outline and cross section of the extrusion dies. Further work would include the selection of candidate items to be extruded and the use of data developed in the actual extrusion process. Subsequently, design and process specifications would have to be formulated and finalized. The process could be ready for use in manufacturing Army aircraft components by 1980.

TECHNOLOGICAL PROGRAM DIRECTION

INTRODUCTION

GENERAL

It is readily apparent from the foregoing technological discussions that an attempt to categorize and prioritize the technological efforts associated with manufacturing technology would be a monumental task and would actually not be appropriate for this RDT&E Plan.

However, it is appropriate to divide MT efforts into the categories listed below and to assess the MT efforts that should be applied to each of the categories:

- Airframe
- Turbine engine
- Drive system
- *Rotor system*
- Aircraft equipment

Figure MT–8 presents a ranking of the relative anticipated effort for each of the five categories.

PRIORITY	CATEGORY	ANTICIPATED PERCENTAGE OF TOTAL MT EFFORT
1	TURBINE ENGINE	27%
2	AIRFRAME	23%
3	ROTOR SYSTEM	20%
4	DRIVE SYSTEM	17%
5	AIRCRAFT EQUIPMENT	13%

Figure MT–8. Relative efforts anticipated by MT category.

TECHNOLOGICAL RATIONALE

Turbine Engine. The development of technology to manufacture existing or anticipated high-performance engines and associated components to overcome existing problems is required. Expected operational characteristics aimed toward more efficient turbine engines are higher operating temperatures and increased power-to-weight ratios. Particular

emphasis will therefore be evident in the MT development of components utilizing ceramics such as silicon carbide or superalloys with high-temperature fatigue life, for example.

Airframe. The manufacturing technology required to produce the airframe (aft or fuselage) and secondary structures such as skins and stringers) must be developed. Considerable effort is anticipated in this area due primarily to emphasis on increasing the strength-to-weight ratio. As a result, particular emphasis is being placed on developing MT for structures made from titanium, composites, and other high-strength/weight materials.

Rotor System. Technology to manufacture metallic and nonmetallic rotor items and associated components such as blades, hubs, or spars must be developed in order to increase performance and reliability. Again, particular emphasis is placed on such high-strength/weight materials as titanium and the composites. As a result, considerable additional effort is necessary to develop the MT processes for rotor items made of these advanced materials.

Drive System. Requirements call for the development of manufacturing methods for moving and non-moving parts and associated components such as shafts, gears, bearings, and transmission housings in order to increase reliability and decrease costs. Primary problems anticipated in the drive system are difficulty and cost in the manufacture of gears and performance problems with transmission housings and gears.

Aircraft Equipment. Considerably less effort is anticipated in the area of MT development for helicopter equipment. The primary reason is that requirements in this area are usually for items that have a low manufacturing development cost, such as cargo slings. Components of critical importance, such as transparent and ceramic armor, are included in this category, however.

DESCRIPTION OF PROJECTS

INTRODUCTION

The primary objective of the AVRADCOM Manufacturing Methods and Technology Program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in the production of Army aviation materiel. The overall goal of the MMT program is to ensure that the Army is able to produce helicopters with maximum performance and reliability at a reasonable cost.

MM&T INTEGRALLY HEATED AND PRESSURIZED TOOLING FOR UTTAS ROTOR BLADES

Project 1787121 will establish criteria for integrally heated and pressurized tooling to replace autoclaves in the production of UTTAS rotor blades. The research and development effort for this project has been accomplished by the Sikorsky Aircraft Division of United Technologies using private funds.

Present technology for rotor blade curing is to layup the skin/honeycomb assemblies, cover them with vacuum bag material, seal the material, check for leaks, move the parts into the autoclave, slow heat up, hold at temperature to cure, slow cool down, remove from autoclave, remove bag, and remove finished assembly from tool. The proposed process would eliminate the use of vacuum bag material by having an integral bag, use the tooling as the cure fixture, rather than place the tooling in the autoclave, and use rapid heat up and cool down rates to reduce cycle time.

IN-PROCESS CONTINUOUS BALANCING HELICOPTER SHAFTING (CAM RELATED)

The purpose of Project 1787123 is to build and demonstrate an automatic machine for the balancing of long hollow helicopter shafting. The end result of the project will be a shaft balancing machine to be used during production of shafting for both current and future Army aircraft.

When long, hollow shafts (such as tail rotor drive shafts) are not perfectly balanced, bearing supports are subjected to excessive stress; and, in the case of shafts designed to operate at supercritical speeds, the shafts themselves are subjected to severe loading when running near resonant frequencies.

Existing balancing techniques are difficult and costly, requiring high speed spinning equipment and relying on unscientific trial-and-error methods. Hughes has developed and demonstrated manually a scientific balancing method that requires only slow, nearly static rotation of the shaft. The method balances all axial stations of the shaft, resulting in a continuous balance which also solves the problem of operation near critical speeds.

T700 ENGINE NOZZLE IN-PROCESS INSPECTION

Project 1787144 will develop an in-process inspection technique for turbine nozzles. Automatic electrical measurement of nozzle areas for air flow and infrared scanning for flow blockages will be developed along with holding fixtures to group nozzle segments as a full assembly.

The feasibility of examining assembled nozzles nondestructively for blockage and air flow volume has been demonstrated by General Electric sponsored research. A prototype automatic flow area measuring device with digital display and printed readout has been developed in addition to electrical area measuring equipment which has been adapted for automatically summing the total flow area of stage 1 nozzles.

This project will speed the necessary area measurement and flow control checks, thereby reducing operational cost. The work will be performed mainly by an industrial contractor (G.E.) engaged in the development of the T700 engine. End products of this project will be nondestructive test equipment and test techniques developed for the solution of inspection and quality control problems associated with small, air cooled, turbine nozzles.

DIFFUSION-BONDED TITANIUM SPAR FABRICATION

Project 1787054 will establish the manufacturing processes for control of continuous seam diffusion bonding of titanium rotor spars, scaling up of machinery and prototype fabrication. This effort will include establishment of tube forming parameters suitable for production titanium tube cold brake forming.

The two methods for manufacturing the titanium rotor spar result in either excessive material usage or require stringent process control, both of which significantly increase the spar costs. The successful development of the continuous seam diffusion bonding process will reduce these cost drivers. Initial tests have shown that near net forming is possible and that the process requires less control. The fabrication and testing of full length (25 ft) UTTAS spars will verify the initial tests.

The end product of this effort will be a data package of the production method for cold brake forming and diffusion bonding of Ti-6Al-4V rotor blade spars. Cost savings for the rotor blade of 35 percent can be realized through proper process control.

ABRADABLE SEALS FOR COMPRESSOR BLADE TIP APPLICATIONS

Project 1787086 will establish a manufacturing technology for production compressor case shroud abradable gas seals for small high-performance gas turbine engines.

The extremely close tolerance between rotating and stationary elements of a gas turbine engine require expensive precision machining to minimize gas leakage. The use of abradable seals allow the rotating member to generate a path in the seal providing a critical clearance between the blade tip and case shroud. The end products are technical reports and an abradable sealing system technology for blade tip applications for small advanced design gas turbine engines. This leads to increased horsepower, decreased fuel consumption, and a decrease in manufacturing and maintenance costs.

COLD ROLLED RINGS TO FINAL SIZE

Project 1787067 will establish manufacturing technology for the production of gas turbine spacers and containment rings to net or near net configurations. This process will replace conventional forging and extensive machining.

Process feasibility has been demonstrated by private industry through completed R&D efforts.

This program will establish production techniques for the economical manufacture of small rings. To achieve this goal, one of several emerging processes of interest will be selected based on their status at the onset of the budget fiscal year. One process utilizes unique ring rolling equipment designed by General Electric and currently in production at their plant for the manufacture of rings 8 in. and larger. An alternative process known as Isothermal Rolling, developed by Solar Corporation, also shows good potential for providing rings in the required size range (i.e., 3 to 8 in. I.D.). The end products of the project include the development of prototype equipment and dissemination of process data to industry.

ISOTHERMAL ROLL-FORGING COMPRESSOR BLADES

Project 1787036 will establish manufacturing technology for producing precision compressor blades by the isothermal roll-forging process. This process will replace the conventional blade manufacturing process.

Large numbers of compressor blades are used in typical gas turbine propulsion engines for helicopters and other aircraft. These components are made of titanium or alloy steels and are expensive due to high fabrication costs.

Recently completed R&D efforts have shown that the new concept of isothermal roll-forging can be applied to the manufacture of compressor blades. Typical airfoil sections have been produced from barstock in one roll pass. Experience shows that the process combines the excellent surface finish and precision characteristic of cold roll-forging with the excellent metal flow in one operation characteristic of hot forging. This combination of advantages has been found to result in a cost saving of more than 50 percent when applied to other metal shaping problems.

PROCESSING OF AIRCRAFT COMPONENTS USING PULTRUDED MATERIALS

Project 1787091 will assess pultrusion processing of multiple fiber combinations and develop the required post-forming operations for partly-cured pultrusions to provide low cost components for applications within the helicopter.

The pultrusion process has not been widely exploited in aircraft manufacture due largely to the limited orientation of fibers and to the fact that sufficient fabrication methods have not been developed to use partly-cured pultruded materials in subsequent processing steps. Complete cure pultrusion has been shown to be a cost effective fabrication technique for structures used in commercial applications such as continuous pipe, structural I-beams, and window channels. What remains to be accomplished is the establishment of methods for processing (e.g., post-forming) partly cured pultruded stock; and for assembly of pultruded stock into components and final cure in place.

ULTRASONIC WELD OF HELICOPTER FUSELAGE STRUCTURES

Project 1787055 is the second year of a 2-year MM&T effort to verify ultrasonic welding as an effective production technique when applied to helicopter fuselage structures. The purpose of this project will be to develop and optimize the ultrasonic welding manufacturing process techniques and to verify the potential cost savings of ultrasonic welding over conventional welding and joining processes (such as hot bonding and riveting). Ultrasonic welding can reduce the cost and increase the speed of welding, thus reducing the cost and lead times of Army procured fuselage structures.

The end product of this project will be the establishment of a process specification (industrial and military) for ultrasonic welding and a final report fully describing the effort accomplished and the ultrasonic welding process information.

ULTRASONICALLY ASSISTED FORMING OF NOSE CAPS FOR ROTOR BLADES

The purpose of Project 1787052 is to develop the production techniques for cold forming erosion resistant nose caps for helicopter rotor blades. Currently, titanium nose caps for the CH-47 modernization, and UTTAS fiber glass rotor blades and stainless steel nose caps for the AAH are being hot formed. The hot forming processing requires long processing times, high-cost tooling and equipment, and expensive chemical etching. Based on results of prior IR&D efforts and demonstrated effects of ultrasonics on forming of other materials, ultrasonic energy will solve the problems associated with the cold forming process, such as force required, spring back, and cracking.

T700 TURBINE ENGINE NOZZLE MANUFACTURING PROCESS

Project 1787104 will develop processing techniques for turbine engine nozzle manufacturing. Previously developed grinding techniques will be optimized for machining nozzles made from cobalt and nickel alloys. This work will be performed mainly by an industrial contractor (G.E.) engaged in the development of the T700 engine.

In applying these techniques to the small size nozzles used in the T700 engine, it is necessary to

scale-up unconventional holding fixtures for grinding nozzle segments as a unit and to optimize the grinding techniques for the particular components. Optimized grinding techniques will result in closer dimensional control, thus improving engine performance and reducing hardware reject losses.

NON-DESTRUCTIVE EVALUATION TECHNIQUES FOR COMPOSITE STRUCTURES

Project 1787119 will provide a manufacturing handbook for non-destructive in-process inspection of composite structures.

A large number of non-destructive testing (NDT) techniques have been developed for and are being used with composite structures with widely varying configurations. NDT methods such as ultrasonic, transmission and reflection infrared, acoustic emission, acoustic holograph, optical holography, and neutron- and X-ray have been used. Various manufacturing defects such as debonds, gaps, overlaps, cracks, wrinkles, fiber breakage, etc., can be detected. The structures examined range in complexity from skins, flat panels, and curved panels through rotor blades.

This project will initially use the composite rotor blade to develop data for the project. Then, once the data is obtained, the information obtained would be applied to other composite structures. Depending on the configuration and stress levels in the structure, various criteria will be established for acceptance or rejection based on number, type, and size of the measured defects. The proposed handbook will list the types of structures inspected, the type of inspection methods used, the defects tested for, and the acceptance/rejection criteria used.

COST EFFECTIVE MANUFACTURING METHODS FOR IMPROVED HIGH PERFORMANCE HELICOPTER GEARS

The demand in helicopter operation for greater reliability of high performance gears at lower cost has required that improved processing and evaluation techniques be instituted. Project 1787155 is concerned with one such improved method, ausrolling, in combination with improved nondestructive evaluation methods to provide a solution for optimizing quality, reliability, and cost. MMT efforts of prior years (Projects 1748148, 1758148, and 1768148) have emphasized the optimization of heat treatments of gears fabricated in commercially available AISI 9310 and modified VASCO X-2 steels. As a result of these efforts, heat treatment processing variables such as carburizing, austenitizing and tempering procedures have been established. However, to ensure effective implementation, it is required that quality control be incorporated in specifying steels for high performance gear applications. Accordingly, one aspect of the program would be to utilize previously developed computerized ultrasonic nondestructive testing techniques for quality control in every stage of processing. This control, coupled with improved metal production, such as electro-slag remelt, and double vacuum induction/vacuum remelt in conjunction with unique metal fabrication methods, typified by ausrolling and cold finish rolling gears, should result in significant improvements in quality and reliability at lower cost. The program will address the manufacture of new spur and helical gears with implementation taking place through carefully structured test and evaluation procedures (e.g., four-square and transmission stand test procedures) that duplicate service environment. This technology will be transferred to gear producers and helicopter manufacturers such as Boeing Vertol, Sikorsky, etc. Based on these efforts, a Gear Producibility and Technical Data Package (Guide) for High Performance Gears will be written and provided as a basis for implementation of these processes in aircraft such as UTTAS, AAH, and CH-47 Mod were the decision to use material such as 9310 or VASCO X-2 steel has been made.

FIBER REINFORCED PLASTIC HELICOPTER TAIL ROTOR ASSEMBLY

Project 1788045 will establish a pultrusion manufacturing technology capable of providing reliable and cost effective composite helicopter tail rotor assemblies. This process will replace the current hand lay-up fabrication procedures.

The development of pultrusion manufacturing technology will enable advanced helicopter tail rotor assemblies with improved performance characteristics and operational life to be used efficiently and cost effectively on Army helicopters. The proposed tail rotor blade project is different from current inventory tail rotors in that a composite material flex beam concept is utilized. The pultrusion fabrication process is a low cost automated process that lends itself to fabrication of structures consisting primarily of continuous unidirectional fibers, such as flex beam tail rotor spars. The end products of this project include technical reports and manufacturing technology

applicable to pultrusion fabrication of flex beam tail rotors. In addition, this project will result in a pultrusion fabrication technology directly applicable to the UTTAS tail rotor. The technology gained from this project will be disseminated to industry and government agencies by both reports and briefings.

SEMI-AUTOMATED COMPOSITE MANUFACTURING SYSTEM FOR HELICOPTER FUSELAGE SECONDARY STRUCTURES

Project 1787183 is a 4-year program to design, fabricate and demonstrate a semi-automated manufacturing system for the production of helicopter secondary structural parts made from advanced composite materials. The proposed system is a continuous in-line automated fabrication approach in which all manufacturing operations are conducted on a preprogrammed "moving line" concept. The system will perform all the manufacturing operations necessary to produce a complete composite structural part. The operations include four stations: station 1, layup of material; station 2, preforming, compaction, and trimming; station 3, final assembly; and station 4, advanced "B" staging.

The proposed system will be adaptable to complete N/C and eventually to an integrated Computer Aided Manufacturing Production Facility for the production of primary helicopter fuselage structural parts.

SURFACE HARDENING OF GEARS, BEARINGS, AND SEALS BY LASERS

Project 1787199 will establish manufacturing technology for surface hardening of gears (now case carburized), bearings (now through hardened), and seals (now ground and polished).

Case carburizing is expensive – requiring much energy, quenching dies, and final grinding. Through-hardened bearings lack impact strength and fracture toughness needed for survivability; they cannot be case carburized nor induction hardened. The end products of the project include technical reports and manufacturing technology applicable to laser hardening of gears, bearings, and seals. These will be disseminated to industry and other Government agencies.

MANUFACTURE OF SPARE ABRADABLE GAS PATH SEAL SYSTEM

Project 1787143 will establish methods for production of sprayed ceramic seals on the turbine section of Army gas turbine engines.

Currently, operational gas turbine engines used by the Army do not employ rub tolerant seal materials in the high-pressure turbine position. Damaging rub interactions between the blade tip and the seal are avoided by providing sufficient clearance to prevent rubbing contact while the engine is cold. However, as the engine heats up, the diameter of the gas path expands, meaning that the engine operates with excessive clearance. The use of sprayed ceramic seals will generate closer operating clearances. The end products are an estimated 2 percent increase in engine efficiency and an inexpensive process that could be incorporated into the Army's engine rework program.

ADVANCED TECHNOLOGY
DEMONSTRATION

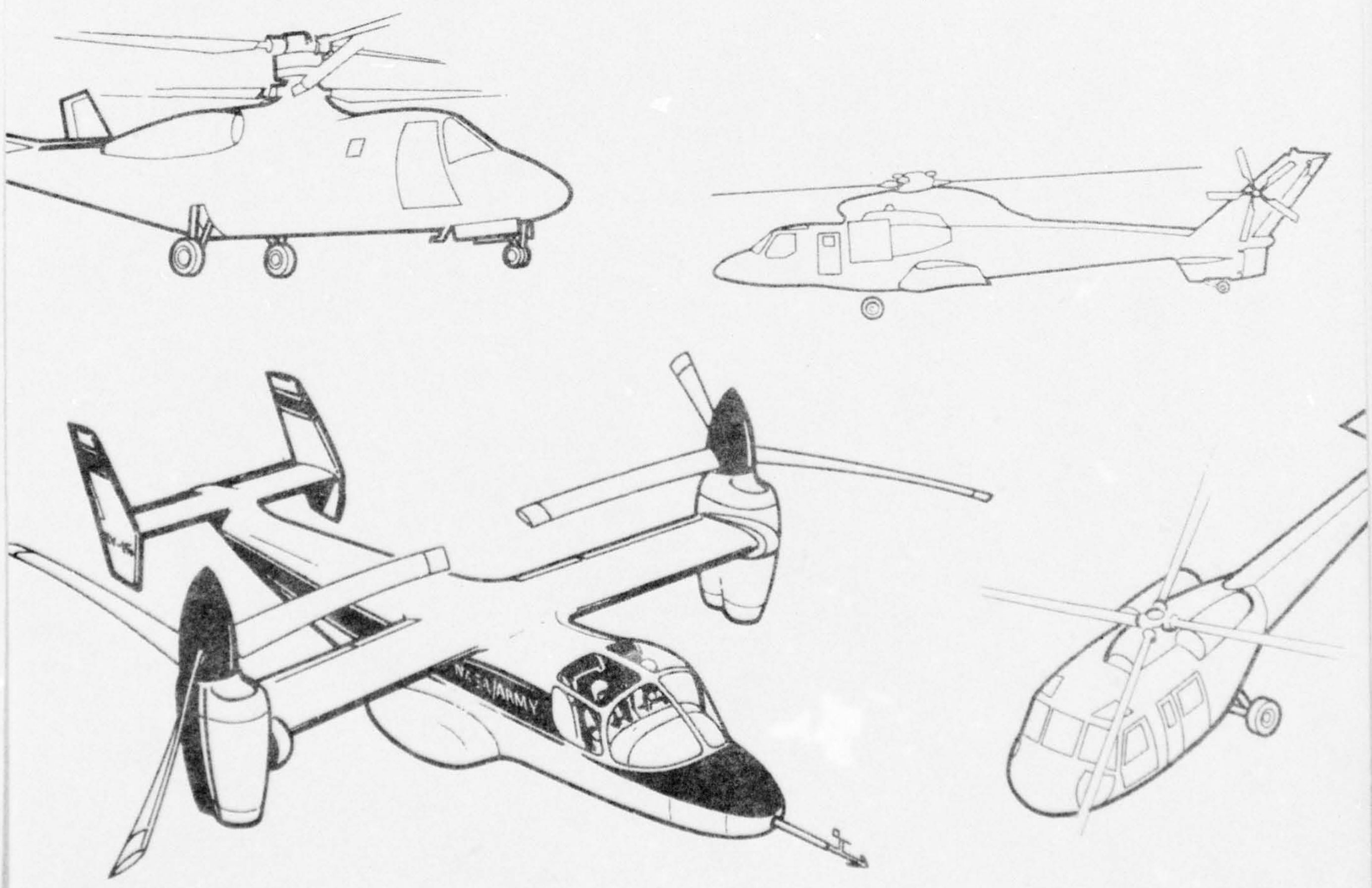
INTRODUCTION

TILT ROTOR AIR VEHICLE

ROTOR SYSTEM RESEARCH AIRCRAFT

ADVANCING BLADE CONCEPT

ADVANCED TECHNOLOGY DEMONSTRATOR ENGINE—800 SHP



INTRODUCTION

Progress in improving the performance of Army helicopters and other VTOL concepts will be paced by the technological advances in propulsion systems, drive systems, rotors, flight controls, and structural materials. Emphasis on performance must be tempered by considerations of maintainability, reliability, and survivability to achieve acceptable operational characteristics.

Although the specific mission requirements have not been defined for various aircraft concepts, it is possible to identify promising concepts and the research efforts required to develop the technology base needed to support these concepts.

Attainment of the increased performance and utility of the aerial vehicles to be introduced into the Army between now and the year 2000 depends directly upon the establishment of a broad technological base of knowledge, experience, and demonstrated concepts.

The programs described in this section were formulated on the basis that advances in state-of-the-art technology can only be made if technology is validated by component or system demonstration in actual or simulated flight conditions. Fundamental technology will be validated in this manner to provide criteria for incorporation into design of future Army vehicles.

TILT ROTOR AIR VEHICLE

GENERAL

A major problem addressed in the discussions of many of the technologies in this plan is the high dynamic loads on the helicopter rotor during cruise operation. These high dynamic loads not only restrict the performance capability of the helicopter but, more importantly, generate the vibrations and noise that result in the fatiguing of structures, components, and aircrew, and in reduced availability, and increased maintenance and support costs. Moreover, in addition to the VTOL capability requirement, several of the Army airmobility missions identified in this document would benefit greatly from the increased productivity that a higher cruise speed could provide. The tilt rotor, one of the candidate aircraft concepts considered for these roles, offers promise of significant improvement in these areas while providing the desirable VTOL characteristics of the low-disc-loading rotary wing aircraft. Therefore, over the past 9 years, the Army has actively supported a program to develop the technology required to enable the implementation of this type of air vehicle. An important element of this effort is currently in progress in a flight demonstration of the integration of all related technologies. The proof of concept program, the XV-15 Tilt Rotor Research Aircraft Project, to accomplish this is being conducted jointly with the National Aeronautics and Space Administration. This activity and follow-on tilt rotor air vehicle programs are discussed in this section.

CONCEPT CHARACTERISTICS

The principal flight modes of the tilt-rotor aircraft (fig. AT–1) are hover or helicopter, transition or tilt rotor, and cruise or airplane.

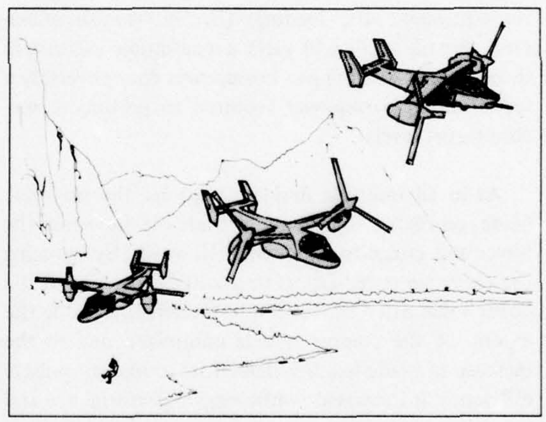


Figure AT–1. Tilt rotor principal flight modes.

The key potential advantage of the tilt rotor concept is that it combines the efficient static lift (hover) capability associated with the low disc loading helicopter with the efficient cruise performance and low vibration of a fixed wing turboprop aircraft with cruising speeds of the order of 300 knots. Eliminating the requirement to operate the rotor in the edgewise flight mode for high speed (cruise) permits the blades to be tailored with a high spanwise twist and camber distribution that significantly reduces induced and profile losses, therefore improving hover efficiency. Figure AT–2 illustrates the effects of the major rotor characteristics on hover and cruise mode performance. The effect of the improved hover efficiency

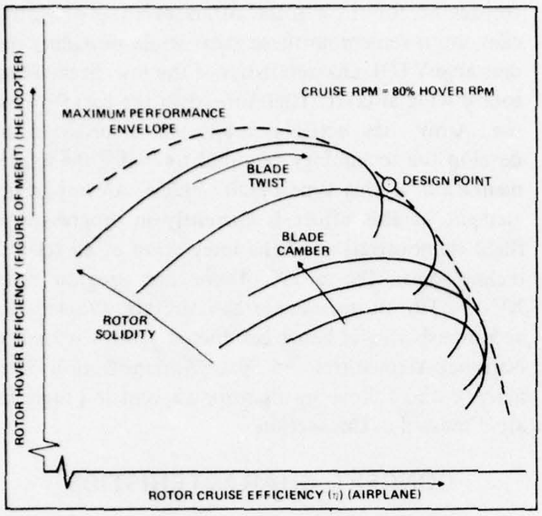


Figure AT–2. Effect of rotor parameters on hover/cruise performance trade-off.

(Figure of Merit) is illustrated in figure AT–3, where, for equivalent disc loadings (i.e., downwash velocities), the tilt rotor will yield a measurable increase in thrust (gross weight) per horsepower (or conversely a reduction in horsepower required to produce a specific thrust level).

As in all multiple design situations, the tilt rotor blade geometry represents a trade-off between the hover and cruise requirements. However, by reducing the rotor tip speed (rpm) to about 80 percent of the hover value after conversion to the airplane mode the extent of the compromise is minimized due to the increase in blade loading. Therefore, cruise propulsive efficiency is increased, while engine performance and transmission/drive system torques are maintained at desirable levels. The moderate tip speeds and non-oscillatory blade loadings of the tilt rotor will also result in a reduced acoustic signature compared to other VTOL concepts.

A significant product of the combination of high efficiency of the tilt rotor in both the hover and cruise flight modes is fuel conservation. For example, the higher rotor performance results in a requirement for smaller engines to perform a typical hover/cruise/hover transport mission. As an additional bonus for mid- to long-range applications, the higher cruise mode speeds (at lower power levels) will also increase productivity [Productivity Factor = (Payload × Delivery Speed)/Empty Weight]. High endurance capability at moderate airspeeds due to a reduction in the

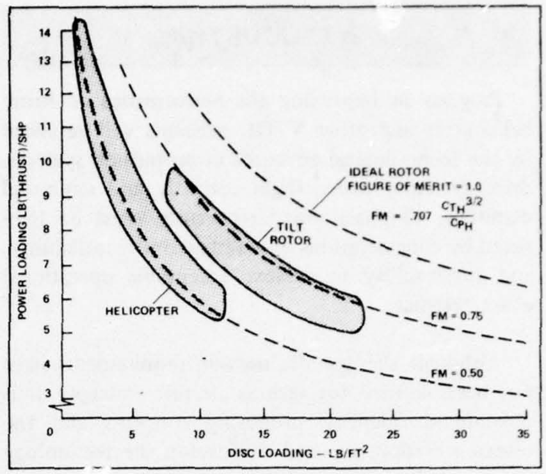


Figure AT–3. Disc loading effect on rotor hover efficiency.

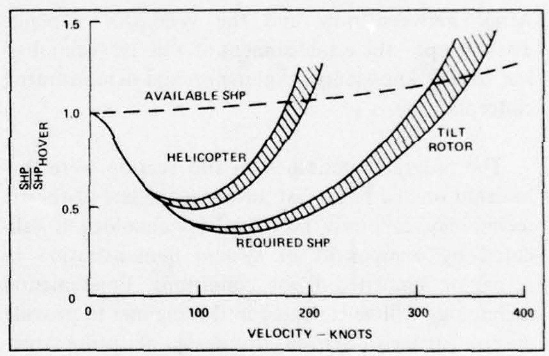


Figure AT–4. Power required comparison.

power required (see fig. AT–4) is another benefit of the fuel conservative tilt rotor.

Because of the efficiency and time advantages (speed) of airplane mode operations, it is anticipated that most tilt rotor missions will use this flight mode extensively. Therefore, the relatively short duration of forward flight in the helicopter mode for these applications will result in a favorable fatigue environment for both the tilt rotor vehicle and the crew, as compared to the helicopter (see fig. AT–5). The use of the wing to sustain lift in cruise flight and the associated reduction in the dynamic loadings on the rotors will also contribute to a reduction of crew fatigue by improving flying qualities and lowering cabin vibration levels. A further result, and perhaps the most significant, is an expected increase in reliability and a reduction in required maintenance.

Additional benefits of the use of low disc loadings include low downwash velocities. Low downwash velocities allow efficient ground operations below a hovering tilt rotor aircraft with improved personnel safety, as well as autorotation capability to achieve a safe descent/flare in the event of a total power loss.

The tilt rotor concept is also unique in that the conversion corridor, (i.e., the band between the minimum and maximum flight speeds throughout the rotor-mast tilting process) is broad (typically greater than 60 knots) and non-critical. Furthermore, the conversion may be stopped and reversed, or the aircraft may be flown in steady-state at any point in the conversion corridor. This feature is expected to provide great flexibility in field operations, enhance survivability because of low-speed agility, and permit the performance of STOL operations at greater than VTOL gross weights.

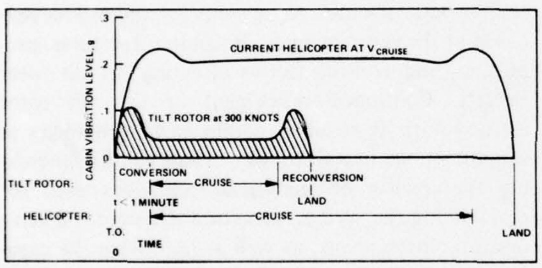


Figure AT–5. Vibration environment.

The two tiltable low-disc-loading rotors, located at the wing tips, are driven by two or more gas turbine engines. The engines may be located in the tilting nacelles mounted at the wing tips, or may be fixed with respect to the wing. A cross shaft system mechanically links the rotors so that power sharing for maneuvers or control is possible and asymmetric thrust in the event of single engine malfunction is avoided. Independent control of each engine/rotor can be maintained should simple cross-shaft failure occur (due to combat damage, for example). The rotor/nacelle tilt mechanism is provided with redundant fail-safe design features, thus preventing asymmetric tilt conditions and binding of the mechanism in any fixed position.

The stiffness and mass distributions of the rotor/nacelle/wing/dynamic drive system are tuned to remain clear of resonances in the range of operating rotor rotational speeds. Special emphasis is placed on meeting both the structural and dynamic stability requirements. Therefore, the aircraft was designed to be free of rotor stall flutter and wing/pylon/rotor dynamic coupling problems throughout the entire tilt rotor operational flight envelope.

The control system in hover is similar to that of a "side-by-side" twin rotor helicopter. Fore and aft cyclic pitch provides longitudinal control and (differentially applied) yaw control, eliminating the need for a tail rotor. Differential collective pitch provides roll control. In the cruise flight mode, control is achieved with conventional airplane control surfaces, although the presence of the rotor cyclic and collective controls would permit, with further development, the use of the rotor in cruise for control augmentation, aircraft stabilization, and gust alleviation. A program for phasing of control functions from helicopter to aircraft type controls as a function of mast angle is applied during conversion.

OBJECTIVES

The following proof-of-concept objectives, directed toward basic tilt rotor air vehicle technology verification, have been established for the current XV-15 Tilt Rotor Research Aircraft Project. The successful accomplishment of these objectives or the identification of resolvable problems is considered to be critical to the continuation of tilt rotor technology development and the subsequent application to civil and military air mobility requirements.

- Experimentally explore, through flight research, current tilt rotor technology that is of interest for the development of useful, quiet, and easily maintainable Army tilt rotor aircraft. Verification of the rotor/pylon/wing dynamic stability and aircraft performance over the entire operation envelope are key elements of this objective.
- Experimentally establish a safe operating envelope and initially assess the handling qualities of the Tilt Rotor Research Aircraft as a basis for the follow-on advanced flight research.
- Investigate tilt rotor gust sensitivity.
- Investigate the effects of tilt rotor disc loading and tip speed on downwash and noise and the effect on hover mode operations.

An advanced flight research program has been formulated to expand the state of the art of tilt rotor handling qualities, operations, and configuration

design. These flight investigations will be performed to achieve the following objectives:

- Perform thorough evaluations of the handling qualities of the Tilt Rotor Research Aircraft and assess areas where additional tilt rotor handling qualities research is required including incorporation and evaluation of gust load alleviation systems and fly-by-wire control systems.
- Determine V/STOL navigation/guidance requirements and evaluate automatic landing systems.
- Develop and evaluate potential methods and procedures for efficient near-terminal operations to reduce congestion and noise and to increase safety.
- Provide data for consideration of design and operational criteria for potential military and civil tilt rotor aircraft relative to certification requirements and Aeronautical Design Standards.
- Investigate alternative or advanced rotor concepts or configuration modifications.

Further flight research will be performed with the Tilt Rotor Research Aircraft to explore the various aspects of use of this concept for typical Army missions – the ultimate objective of this program. As a part of the investigation of mission suitability, all related technological characteristics (such as maintenance, human factors, and safety) will be explored.

IMPLEMENTATION PLAN

The tilt rotor concept appears especially well suited for military applications for reconnaissance and surveillance, search and rescue, utility, and medium-lift missions. IOC dates established for vehicles to satisfy these missions will set the pace for the further development of all pertinent technologies.

The plan to accomplish the necessary technical goals is composed of the following eight elements, all of which are required prior to entering a production prototype program:

- Methodology development
- Model tests
- Full-scale component and subsystem tests
- Air vehicle design studies
- Flight simulation investigations
- Systems integration and proof-of-concept flight tests
- Advanced technology investigations flight tests
- Mission suitability flight tests.

Tilt rotor technology was initiated with the XV-3 flight program in the 1950s. This program was based on the direct application of existing helicopter analyses. Although the XV-3 program demonstrated the feasibility of the tilt rotor concept at low speeds, several problems requiring further research were identified in the areas of rotor/pylon/wing stability, flight stability, and performance. The recognition of these problems led to the derivation of sophisticated tilt rotor analytical models during the late 1960s, particularly in the structural dynamics, rotor performance, and stability and control disciplines. These mathematical models were developed by the integration of several basic sciences to account for the interdependence of the aerodynamics, dynamics, structures, propulsion, and control factors affecting the tilt rotor aircraft. Continued refinement of this tilt rotor methodology is required within each technology in support of the overall progam. Plans call for improving the quality of analytical techniques used for determining the various structural dynamic and aerodynamic interactions, as well as improving the capability of utilizing complex computer programs as design tools. The availability of new experimental data will enable continual upgrading of the analytical methods.

The application of model test techniques toward verifying the performance, structural stability, and flight stability of the tilt rotor aircraft will continue as an essential part of the program. Improved modeling techniques, comprehension of scale effects, the development of effective methods of isolating the model from wind tunnel wall effects during low speed or transition flight, and techniques for properly simulating ground effects and atmospheric turbulence are required. Specific areas of research related to the tilt rotor aircraft include the continuing development of the rotor system (hingeless, gimballed, etc.), determination of rotor/pylon/wing dynamic stability characteristics of new configurations, investigations of rotor wake/wing interaction and tail interaction effects, and the development of stability augmentation and gust alleviation systems. State-of-the-art aeroelastic modeling techniques are used to provide the dynamic scaling necessary for some of these tests.

Investigations of the performance, dynamic stability, and functional characteristics of full-scale tilt rotor aircraft components will continue as part of the XV-15 program to minimize the technical and cost risks. Among the components and subsystems to be examined are the transmission and drive system, the rotor control system including the applicability of a fly-by-wire control system, and the rotor/pylon/wing assembly. Correlation with model test data and analytical data will be examined continually to assess the quality of the technology base and to evaluate the requirement for additional fundamental research.

In addition to the design of the research aircraft, continuing air vehicle design studies are required to determine the adequacy of tilt rotor technology to optimize configuration design for an Army airmobility mission. Trade-offs in performance, weight, cost, noise, and other factors (such as maintainability or transportability) must continue to be weighed. Achieving unique design requirements imposed by the particular mission will rely on the application of the advances to the state of the art made in each of the technologies derived from the foregoing methodology and test programs.

XV–15 RESEARCH AIRCRAFT

A complete integration of all technologies was conducted in the design of the XV-15 Tilt Rotor Research Aircraft. This aircraft (shown in figure AT–6) is the minimum size vehicle capable of demonstrating the generic full-scale flight characteristics of the concept. Design and configuration data for the XV-15 are shown in table AT–A. A stability and control augmentation system (SCAS), a high-sink-rate landing gear, a ground adjustable variable incidence horizontal tail, an emergency egress system, a force feel system, and fail-safe or fail-operational components and subsystems are included in this design. Provisions for advanced avionics for automatic VTOL terminal area operations (V/STOLAND) and a gust load alleviation system are also incorporated. Research capability ensured by providing high control power, adequate installed power, adequate payload in the VTOL mode, adequate cabin volume for instrumentation or other mission payload, and more than 1 hr of fuel for research missions (up to 1.1 hr of hover flight).

The rotors, transmissions, and drive systems have been designed to enable variations of tip speed to study its effects on hover performance, noise, stability and downwash and on cruise performance, gust sensitivity and noise.

Flight simulation investigations have been conducted and additional tests are planned to complement the tilt rotor flight test program. The simulations provide a means of assessing handling characteristics, configuration variations, flight operation procedures, emergency procedures, and SCAS and GLAS (gust load alleviation system) characteristics. The simulators are also used for pilot familiarization and training.

The fabrication and proof-of-concept flight tests of the research aircraft are important milestones in the Army tilt rotor technology program. Basic flight safety and flight envelope boundary exploration will be conducted by the contractor following tests in the NASA-Ames 40- by 80-ft wind tunnel. Additional flight research to examine structural stability, assess handling qualities and study generic tilt rotor aircraft flight characteristics and the effects of gusts, tip speed, and disc loading will be performed jointly with NASA. These flight investigations form the foundation for the advanced flight research program. The initial hover and helicopter mode flights of the XV-15 were successfully conducted by the contractor in May 1977 (see fig. AT–7).

The Army and NASA will continue with the joint flight test program beyond the basic proof-of-concept flights. Research into gust load alleviation systems, handling qualities, alternative or advanced rotor concepts, and flight control systems are planned. The data resulting from this investigation may be instrumental in formulating design and operational criteria and specifications for advanced Army air mobility tilt rotor applications. Certain flight phenomena may warrant additional analytical investigations, model tests, flight simulations, and further flight tests.

The Tilt Rotor Research Aircraft will be used as a tool to assess Army air mobility mission suitability. Factors such as hover out-of-ground-effect, climb capability, loiter and cruise performance, maximum speed capability, handling qualities, maneuverability, pilot work load, autorotation capability, maintenance requirements, and noise, radar, IR, and visual detection signatures will be examined. The XV-15 Tilt Rotor Research Aircraft was designed and built under an experimental shop approach using a maximum of existing hardware; therefore it is not optimally sized

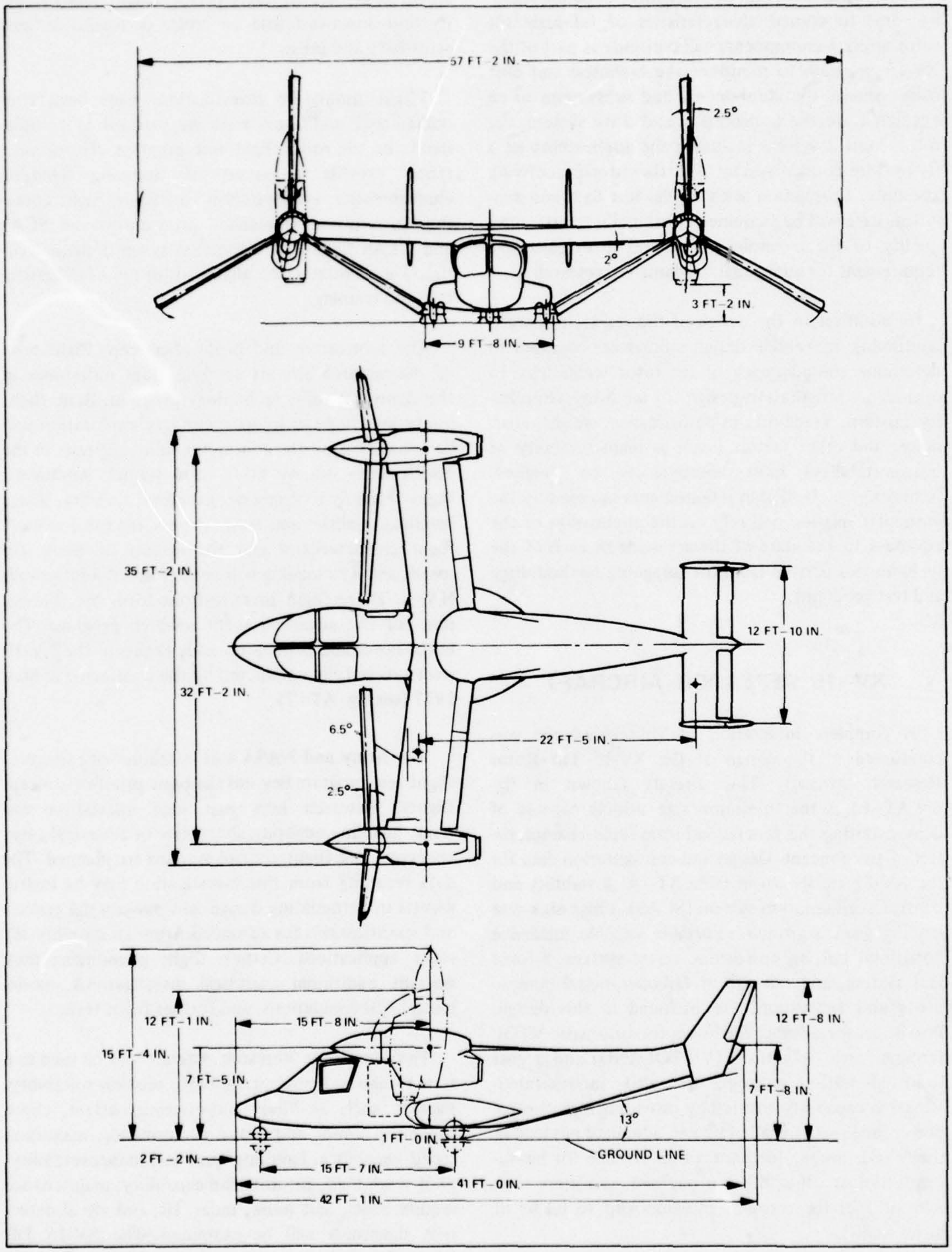


Figure AT–6. XV-15 Tilt Rotor Research Aircraft.

TABLE AT–A
DESIGN AND CONFIGURATION DATA OF XV-15 RESEARCH AIRCRAFT

CHARACTERISTICS	DESIGN	REMARKS
Design/Max VTOL GW	13,000/15,000 lb	10 fps Rate of Sink L.G. @ DGW
Useful Load at Design VTOL GW	3180 lb	Incl. 1170 lb of Research Equip., Crew-400 lb, 1 hr Mission Fuel
One Hour Rsch. Mission Operating Wt	12,735 lb	Crew-400 lb, Fuel 1150 lb + 10 min Res.
Wing Loading	77 psf	@ 13,000 lb DGW
Rotor Disc Loading	13.2 psf	@ 13,000 lb DGW
Rotor Design Tip Speeds		
Hover/Cruise	740 fps/600 fps	@ 565 rpm/458 rpm
Limit Speeds		
Cruise (level flight)	332 knots (TAS)	@ 16,400 ft DGW, Max Torque Limit, Contingency Power
Dive	364 knots (TAS)	@ 12,800 ft DGW, M = .575
Helicopter Mode	140 knots (TAS)(Max)	@ Mast Angle = 75 degrees, S.L., Blade Endurance Limit
Airplane Mode	120 knots (TAS)(Min)	@ 1.2 V_{stall}
Maximum Conversion Rate	90 degrees/11 sec	
Limit Load Factors		
Symmetrical Flight	+3.0g–1.0g	Design GW
Asymmetrical Flight	+24g–0.8g	Design GW
Symmetrical Flight	+2.3g–0.75g	Maximum GW
Noise @ 500 ft Sideline	90 PNdb	Most Noise-Critical Condition
Endurance (Min)	1.1/2.2 hr	Hover @ S.L. Std/Cruise @ 10,000 ft
Design Life		
Airframe	5,000 hr	
Rotor	1,500 hr	
XMSN & Dynamic Components	3,000 hr	
Dimensions		
Overall Height	15.3 ft	Hover Mode
Overall Width	57.2 ft	Rotors Turning
Overall Length	42.1 ft	Without Instrument Boom
Wing		
Area	169 sq ft	
Span	32.17 ft	Between Rotor Axes
Dihedral	2 degrees	
Aspect Ratio	6.12	
Chord	5.25 ft	
Thickness Ratio	.23	
Sweep	–6.5 degrees	Forward from Root
Flap/Flaperon Area	5.5/10.1 sq ft	Per side
Horizontal Tail		
Total Area	50.25 sq ft	
Span	12.83 ft	
Aspect Ratio	3.27	
Elevator Area	13 sq ft	
Vertical Tail		"H" Tail, Two Vertical Panels
Total Area	50.5 sq ft	
Span	7.18 sq ft	Per Panel
Sweep of 1/4 Chord	31.6 degrees	Upper Section
Effective Aspect Ratio	2.33	
Rudder Area	7.5 sq ft	Both Panels
Rotor (Type)	Gimballed	Hub Spring Flapping Restraint
Number of Blades	3	
Diameter	25 ft	
Blade Chord	14 in	Constant
Total Solidity	.089	
Engines (2)(Type)	LTCIK-4K	Lycoming T53, Mod.
Takeoff SHP/SFC	1,550/.57	SHP per Engine
NRP SHP/SFC	1,250/.600	

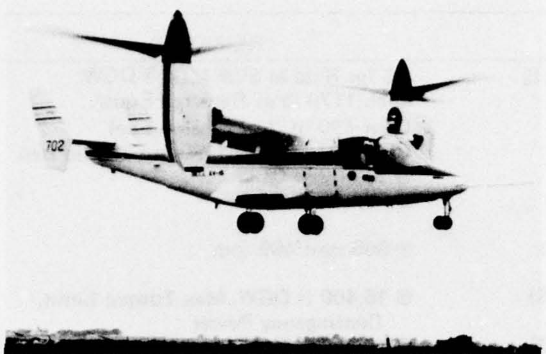


Figure AT–7. In-flight photo of XV-15.

or configured for the particular requirements for any specific Army air mobility mission. However, the vehicle is sufficiently versatile to demonstrate and explore many of the various mission performance and operational factors. The Tilt Rotor Research Aircraft is also a suitable test bed for advanced VTOL avionics for all-weather operation and area navigation investigations. The application of the STOL mode and the use of intermediate rotor mast positions will be studied during this flight test period. It is expected that the proof-of-concept, and some of the advanced flight investigations, of the XV-15 aircraft will provide sufficient verification of tilt rotor analytical methodology and small scale empirical data to allow initiation of an Army System Development Program based upon the tilt rotor concept. As in the application of the helicopter and fixed wing aircraft, a continuing supporting research and technology program will be conducted to maintain world leadership in this field.

ROTOR SYSTEM RESEARCH AIRCRAFT

GENERAL

Since the mid-1960s, the Army and NASA have conducted several independent studies to determine methods of improving the capabilities of rotor flight research on an economical and timely basis. Results of these studies prompted the establishment of an Army/NASA working group in January 1971 to determine if a commonality existed in both agencies for rotor flight research, and if so, what system would best provide a capability to achieve common research objectives. It was concluded that an extensively instrumented flying test bed, capable of accepting and accurately testing new rotor concepts as they became available for "proof of concept" flight research as well as providing a unique test capability for technology verification on existing rotors, offered the best solution.

The Rotor Systems Research Aircraft (RSRA) will fly as a pure helicopter, a compound helicopter, and as a helicopter simulator, where the aircraft wings, drag brakes, auxiliary propulsion engines, and elevator will be used to react the main rotor being tested. This last mode provides a quick, thorough, and cost-effective method of mapping the performance characteristics of test rotors.

CONCEPT CHARACTERISTICS

GENERAL

The RSRA has unique capabilities that make it a versatile research tool. The various subsystems that provide these capabilities are described below.

CONTROL SYSTEM

The versatility of a research aircraft is dependent on the type of control system incorporated into the vehicle. The RSRA has fixed-wing-type aerodynamic control surfaces in addition to the conventional rotor controls. A computer-controlled fly-by-wire system, operating through a mechanical system, is used because it makes it possible to readily adapt the control system, through the computer logic, to the control requirements of a wide variety of rotor systems. This system permits rapid modification in the control authority of both the rotor controls and the aerodynamic surface controls in order to provide the proper integration and control harmony necessary for flight tests of rotary wing compound helicopter concepts. The control system incorporates provisions for performing preprogrammed evaluation maneuvers such as repeatable step or ramp inputs in order to rapidly and accurately acquire flight test data. The computer-controlled fly-by-wire system is used by the research evaluation pilot; the mechanical system is used by the safety pilot.

DATA SYSTEM

An essential feature of the Rotor System Research Aircraft is its ability to obtain in-flight measurements

of the vehicle state (speed, load factor, etc.) and the forces and moments of the rotor, wing, auxiliary propulsive system, and tail rotor system. Sensors installed in the vehicle are compatible with the Langley Research Center developed Piloted Aircraft Data Systems (PADS). These and other data recording or transmitting devices are compatible with the Langley Research Aircraft Ground Station in order to provide on-line monitoring of tests as well as rapid and detailed assessment of rotor and vehicle characteristics. These systems are in use during aircraft acceptance testing; a similar capability will be made available at Ames Research Center where the RSRA will be operated.

VIBRATION ATTENUATION SYSTEM

Since the research aircraft will be flown with numerous rotor systems, covering a wide range of dynamic characteristics, the vehicle has a rotor mounting system that is adaptive to the different rotor systems, along with a system to attenuate significant rotor system vibratory loads. Two different mounting systems are being developed. One is a direct rotor-to-balance mount and the other is an active rotor balance isolation system that provides a system capable of attenuating vibrations from almost all rotor systems.

EMERGENCY CREW ESCAPE SYSTEM

Although not directly related to rotor systems research, an emergency escape system for the three crew members has been provided. The technique being used provides pyrotechnic blade severance and sequential upward extraction of the crew. A second emergency mode allows blade severance followed by automatic flight control adjustment to allow the aircraft to return to base as a fixed wing aircraft.

OBJECTIVES

The objective of Rotor Systems Research Aircraft research is to develop two versatile flight vehicles to provide economical rotorcraft test data in the real and dynamic environment of flight. These research aircraft provide research capabilities that cannot be duplicated in ground-based facilities and that previously have been prohibitively costly because of the need for specialized vehicles for each new rotor system.

The versatility of the Rotor Systems Research Aircraft permits:

- Verification of existing and new rotorcraft technology offering potential solutions of existing or future problem areas.
- Economical flight research on a wide variety of promising new rotor concepts.

IMPLEMENTATION PLAN

GENERAL

The implementation plan is defined in terms of vehicle development, other development activities, and vehicle operations with completion of vehicle development as the primary activity in FY78. These elements are directed toward substantially increasing understanding of rotorcraft characteristics and advancing the state of the art in a cost effective manner.

VEHICLE DEVELOPMENT

Vehicle Definition. A technical team of the Army Research and Technology Laboratories and NASA-Langley personnel reviewed the research requirements of each agency in an effort to define the vehicle characteristics necessary to meet the requirements. The team defined the performance capabilities, systems requirements, and special features for an aircraft capable of performing the desired research mission.

Predesign Studies. A request for proposals was issued to the helicopter industry to obtain predesign studies to:

- Define vehicle configurations that would accomplish the Government's objectives and goals.
- Assess trade-offs between technical requirements and costs.
- Identify and assess potential technical risk areas and indicate technology development required.

Two respondents, the Bell Helicopter Textron and the Sikorsky Aircraft Division, United Aircraft Corporation, were awarded contracts for these studies in December 1971. The study results identified two possible vehicle configurations to accomplish the objectives of the Government.

Vehicle Design, Fabrication, and Test. The vehicle specifications developed from the contracted studies

and in-house efforts were used to establish the final vehicle specifications and requirements for issuance of an RFP in March 1973, for the vehicle design and fabrication. Bell Helicopter and Sikorsky Aircraft responded to the RFP. In September 1973, the Sikorsky Division was selected for negotiations and was awarded a contract effective November 5, 1973. Sikorsky finalized its design for the Critical Design Review held in June 1975. Aircraft No. 1 had its first flight on October 12, 1976 and has completed 14 hr of testing in the helicopter mode. It is entering a flight program at Wallops Flight Center where the compound configuration components are added one at a time for testing. The total compound flight acceptance program will be completed by mid-1978 and the aircraft will be transfered to Ames Research Center. Aircraft No. 2 is scheduled for first flight early in the last quarter of 1977 and will be used to develop the active isolation system. Figure AT–8 is an in-flight photograph of the RSRA in the helicopter configuration; design and configuration data are listed in table AT–B.

Figure AT–8. In-flight photo of RSRA in helicopter configuration.

Developmental Activities for Future Rotor Systems. To date, several developments have been completed and several others are under way to ensure incorporation capability of future rotor systems on the RSRA. Development of these capabilities is necessary to ensure that the personnel conducting research after delivery of the aircraft will have the necessary analytical tools and test techniques to ensure proper integration of new rotor systems of the RSRA.

- *NASTRAN Model.* The contractor has developed a NASTRAN finite-element model representing major structural elements of the RSRA air vehicle system. It has 9000 static degrees of freedom and 300 dynamic degrees of freedom. This model was used for structural sizing of members, calculations of internal loads, and for calculating natural vibration modes of the vehicle in the frequency range necessary for tuning the airframe for the installation of new rotor systems.

- *Active Rotor/Balance Isolation System Model.* An intensive analysis was conducted during the first 9 months of the contract to establish detailed specifications for the active isolation system. Analytical models were established to represent the impedance of the isolation system and impedances of several representative research rotors. These impedance models were incorporated into systems dynamics models, which were used for system design purposes, taking into account the influence of active isolation parameters on the following areas: airframe, vibration, control, mechanical stability, aeroelastic stability, and stability augmentation. These models provide the personnel conducting research operations with the capability to determine the isolator system adjustments required when unusual rotor systems are installed.

- *Control System Capability.* As a part of the development of the control system, additional flight control capability is being incorporated. The RSRA will be capable of operating in a high-resolution model following control mode. This capability offers to the rotor systems researcher the flexibility of prescribing aircraft control motions that are tailored to the specific rotor system being investigated. In addition, the RSRA control system will be capable of providing automatic stabilization of the rotor condition (forces and moments) and/or the vehicle flight path. This capability allows the precise setting of test conditions during research measurement flights.

- *Simulation.* Basic equations of motion and supplementary data have been developed and programmed into a flight dynamics analytical model, fixed base pilot-in-the-loop simulation at Langley Research Center, and moving base pilot-in-the-loop simulation on the flight simulator for advanced aircraft at the Ames Research Center. The data include results of model wind-tunnel test. Analysis and simulation capabilities include flight as a helicopter, as

TABLE AT–B
RSRA DESIGN AND CONFIGURATION DATA

		Lower Horizontal Stabilizer (Except Helo)	
Design Gross Weight, Compound		Area	88.3 sq ft
Mission	26200 lb	Span	22.5 ft
Gross Weight, Hover Mission	18400 lb	Chord (mean)	3.93 ft
Weight Empty, Compound		Elevator Area	12.5 sq ft
Configuration	21162 lb	Incidence	±8° geared
Weight Empty, Helicopter			to stabilizer
Configuration	14630 lb	Upper Horizontal Stabilizer (Except Helo)	
Main Rotor System (Sikorsky H-3)		Area	17.2 sq ft
Diameter	62 ft	Span	8.58 ft
Number of Blades	5	Chord	2.04 ft
Chord	1.52 ft	(Helo)	
Normal Tip Speed	685 ft/sec	Area	35.4 sq ft
Blade Twist	-8	Span	13.25 ft
Tail Rotor System (Sikorsky H-3)		Chord	2.78 ft
Diameter	10.6 ft	Vertical Stabilizer	
Number of Blades	5	Area (Upper and Lower)	101.1 sq ft
Chord	0.612 ft	Span	15.9 ft
Normal Tip Speed	685 ft/sec	Chord (mean)	6.83 ft
Blade Twist	0	Rudder Area	24.8 sq ft
Wing		Turboshaft Engines	
Area	369.9 sq ft	Type	T58-GE
Span	45.1 ft	Military Rating, SLS	1400 HP
Airfoil Section	NACA $63_2$415	Main Gearbox (Sikorsky H-3)	
Aspect Ratio	5.52	Power Rating, 30 Minutes	2500 HP
Variable Incidence Range	-9° to +15°	Turbofan Engines	
Taper	0.66	Type	TF34-GE-400A (2)
		Military Rating, SLS, Static	8159 lb
		Military Rating, SLS, 300 knots	5340 lb

a compound helicopter, and as an airplane. These simulations have been used for evaluating rotor blade severance and will be used for evaluating effects of new rotors.

OTHER DEVELOPMENT ACTIVITIES

General. Technology for the Rotor Systems Research Aircraft has been demonstrated. However, effective utilization of the vehicle will require development of supporting technology in order to conduct a wide range of flight research programs with confidence both as to technological contribution and safety. Prior to flight tests, rotor concepts will undergo logical steps of preparation including detailed analysis and appropriate wind tunnel tests. Several programs under way in support of current rotor developments will yield methods and equipment very generally applicable in this preparation stage.

Helicopter Model System for the Langley V/STOL Wind Tunnel. The Langley V/STOL tunnel has proven especially suitable for investigation of helicopter system characteristics. A generalized helicopter rotor model has been developed under contract and will obviate significant delays in performing rotor test programs, utilizing much more fully the potential of this tunnel. The model accommodates rotor diameters up to 12 ft and is designed for both performance, stability and control testing. Some features that indicate its generality are:

- Range of fuselage contours and representations of gunship, transport, and commercial helicopter configurations.
- Articulated, rigid, or teetering rotors.

- Provisions for wing installation with high, mid, and low positions.
- Provisions for tail rotor and tail surfaces.

The model was delivered with the RSRA fuselage and a four-bladed articulated rotor. Testing at the Langley Research Center was successfully completed confirming the RSRA design.

Rotor Dynamics Wind Tunnel Model. An existing wind tunnel model for study of rotor aeroelasticitiy was improved to provide a general hub fixture. These improvements allow accommodation of 10-ft-diameter elastic rotors, either articulated or hingeless soft inplane. The fuselage is rigid with variable inertias and the model mount incorporates a variable stiffness feature. This model was modified for use in the Langley Transonic Dynamics Tunnel (but not at transonic speeds). However, it may be used in any tunnel of comparable size that has sufficient power for the model rotor drive system.

Flight Simulation Mathematical Model. A flight simulation mathematical model has been developed at the Langley Research Center. It includes an aeroelastic blade representation, body degrees of freedom, and wake representation. Output includes loads, stability and control data, and identification of potential aeroelastic instabilities. This simulation is being used to help define the test program.

Rotor Feedback Study. In December 1974, Sikorsky Aircraft completed a contracted study consisting of analytical and simulation studies followed by in-flight demonstrations of techniques for employing blade motion electronic feedback signals as primary control input shaping functions. This investigation provided engineering data concerning signal conditioning techniques, allowable gains, and stability characteristics of various feedback signals in the control network. In addition, the results have general application in the areas of rotor gust response suppression, high-speed helicopter control sensitivity, and compound helicopter rotor-wing lift control.

VEHICLE OPERATION

Calibration and Acceptance Flights. Prior to Government acceptance of the two Rotor Systems Research Aircraft in FY78, the contractor will conduct flight tests at the NASA-Wallops Flight Center. These tests will demonstrate the structural integrity and safety of flight, develop the recommended procedures for normal and emergency flight operations, and establish the basic stability and control characteristics of the aircraft. Government pilots will participate in the contractor's flight test program.

Research Flights. Initial research flights will include a total exploration of the characteristics of the delivered RSRA rotor. Data from this testing will find direct application in verifying analysis technology. The Navy-developed S-61 composite rotor, which includes advanced airfoil and planform technology, is being studied as a candidate for early testing. Studies are under way to identify prime candidate rotor systems for future testing. Numerous candidates are available and limited resources will dictate careful consideration prior to final selection.

Operations Support. Ground support services for supporting R&D flight operations will be provided by contract under subsequent R&D programs.

ADVANCING BLADE CONCEPT

GENERAL

The operational flight envelope of conventional helicopters is typically limited by vibratory loads in the rotor system as retreating blade stall and compressibility problems are encountered. The flight envelope may be expanded somewhat by increasing rotor sizes and/or adding wings to generate the required lift. Auxiliary propulsion to provide horizontal thrust in combination with wings and "rotor slowing" permits additional expansion of the flight envelope. The major disadvantage of these concepts is that the wings add weight, drag, and complexity.

A theoretical study of a coaxial rigid rotor system, undertaken by Sikorsky Aircraft in 1965, indicated that such a system has potential to overcome or reduce the limitations of conventional and "winged" helicopters. This approach called for lateral displacement of each rotor's resultant lift onto the advancing side of its respective disc, by an amount required to maintain optimum airload distribution. This concept, designated the Advancing Blade Concept (ABC), together with the means of selectively positioning the lift vectors, was awarded US patent No. 3,409,249 in 1968.

From 1967 to 1969, Sikorsky Aircraft and United Aircraft Research Laboratories conducted a series of

experimental programs to develop and test dynamically scaled ABC hardware. These and other investigations indicated that the ABC system was practical and that full-scale hardware could be developed.

A 40-ft-diameter rotor system, designed for a 14,500-lb lift and a maximum speed of 230 knots, was built, whirl-tested, and observed to be aeromechanically stable and structurally sound. To evaluate the system in forward flight, the instrumented ABC rotor was installed in the NASA-Ames Research Center 40-ft by 80-ft wind tunnel and tested at 25 combinations of flight conditions up to a maximum advance ratio of 0.91 and up to an advancing blade tip Mach number of 0.83. Results verified the aerodynamic and structural potential of this concept.

The Army awarded a contract to Sikorsky Aircraft in December 1971 to design, fabricate, and test a helicopter that incorporates the ABC rotor system. The program, currently in progress, is directed toward demonstrating the feasibility and evaluating the performance of the ABC rotor system through flight test.

CONCEPT CHARACTERISTICS

The Advancing Blade Concept is a co-axial, counterrotating, "rigid" rotor with several potential advantages over "standard" rotor systems. With this concept, the aerodynamic lift in forward flight is carried primarily on the advancing blades and is not limited to that which can be developed on the retreating side of the rotor disc. This largely eliminates the problems of retreating blade stall and enhances maneuver capability. As with other coaxial helicopters, a tail rotor is not required for antitorque purposes; yaw control at lower speeds is produced by differential main rotor torque. The "rigid" rotor without flapping hinges, lead-lag hinges, and associated hardware eliminates the maintenance normally required for these components. Super-stiff rotor blades preclude excessive deflections under high loads and permit rotor slowing for high-speed applications where the advancing blade tip Mach number must be kept below approximately 0.85. Potential advantages may be summarized as follows:

- Ability to overcome some of the aerodynamic limitations of conventional rotors
- Superior maneuverability
- Reduced complexity
- Deletion of tail rotor and associated hardware
- Compact configuration
- High-speed capability with horizontal thrust augmentation

The ABC rotor demonstrator aircraft was designed to demonstrate the entire range of rotor capabilities using only the basic rotor system for low-speed operation as a pure helicopter, but employing turbojets to explore high-speed capability of the same rotor design.

The six-bladed, coaxial rigid rotor system is essentially the same as that used in full-scale tests conducted in the NASA-Ames 40-ft by 80-ft wind tunnel. Figure AT–9 is a general arrangement drawing of the XH–59A ABC demonstrator aircraft. Specific characteristics of the demonstrator aircraft are also shown.

Power to the rotor system is supplied by a UACL/Pratt & Whitney PT6T-3/T-400/Twin Pac rated at 1800 shaft horsepower and driving through a transmission system derated to 1500 hp. This system provides dual engine safety and sufficient power to hover out of ground effect at maximum gross weight at sea level with an ambient temperature of 90° F. Auxiliary thrust for maximum performance is provided by two Pratt & Whitney J60 turbojets. These units are not installed during the pure helicopter portion of the evaluation.

The flight control system combines control of the coaxial rotor system with elevator and rudder control. The cockpit controls consist of a cyclic stick for pitch and roll control, a collective stick for vertical control, and pedals for directional control. The collective stick changes the blade pitch angle equally on each rotor for rotor thrust control. The cyclic stick changes the blade angle cyclically and equally on each rotor for rotor pitch and roll moment control. The pedals change the blade angles collectively, but equal and opposite, on each rotor (differential collective pitch) for directional control. Unique to the ABC rotor system is the ability to change the cyclic pitch blade angles of each rotor differentially to load or unload the advancing, high dynamic pressure side of each rotor to optimize rotor efficiency and minimize blade stresses. Full rotor lift capability can be maintained in high-speed flight; high-lift capability is available for load factor development at all speeds. In addition to rotor controls, the longitudinal cyclic

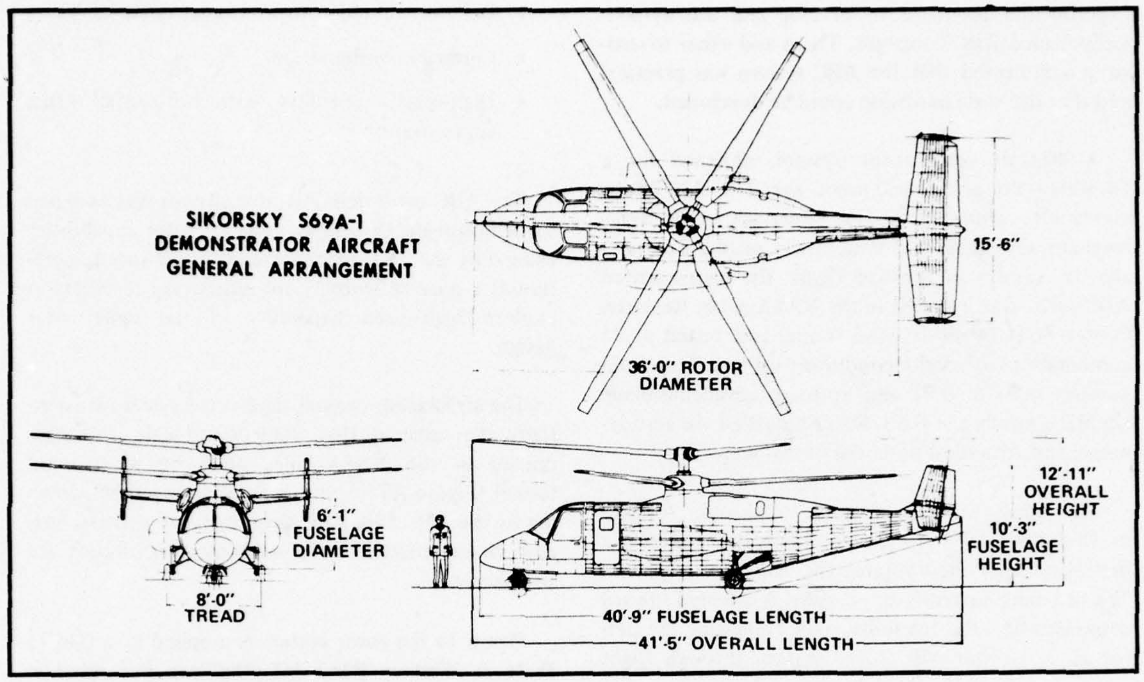


Figure AT–9. XH-59A ABC demonstrator aircraft general arrangement.

stick can be connected directly to the elevators and the pedals are connected directly to rudders. Geared tabs are installed on the rudders and elevators to reduce the stick and pedal forces. The tabs have an electrically actuated link, controlled from the cockpit, to permit trimming the stick and pedal forces. A rotor differential collective pitch trim control is also installed in the cockpit to trim differences in rotor torque in level flight.

OBJECTIVES

The following general objectives have been established for the XH-59A Advancing Blade Concept Flight Research Program:

- Investigation of ABC rotor behavior during a broad spectrum of test conditions.
- Definition of ABC rotor inherent capabilities, limitations, and best operational conditions.
- Investigation of dynamic loads, vibrations, stability, control, and handling qualities, maneuver capability, autorotational entry and aerodynamic performance throughout the operational flight envelope.

Specific objectives include the following:

- Demonstration of the ability to hold sustained load factors of 2.5 g at discrete speeds from 70 knots to 170 knots with satisfactory maneuvering stability, acceptable blade tip clearances, and stress levels in all critical components limited to not more than 150 percent of their fatigue endurance limits.
- Demonstration of cockpit vibratory levels that do not exceed MIL-Spec requirements. This demonstration is to be accomplished without an active vibration isolation system installed.
- Demonstration of flying qualities that are compatible with MIL-Spec requirements. This demonstration is to be accomplished without the need for unduly complex types of stability augmentation or control systems.

IMPLEMENTATION PLAN

In December 1971, the Applied Technology Laboratory of the Army Research and Technology Laboratories awarded a contract to Sikorsky Aircraft Division of United Aircraft to design, fabricate, and flight test an ABC-configured research aircraft. Specific

design requirements were kept to a minimum to provide the necessary trade-off flexibility in arriving at a balanced but, of necessity, highly compromised design. Aircraft target design speed was 140 to 170 knots in the helicopter mode and up to 300 knots in the compound helicopter mode with two J-60 turbojets providing horizontal thrust. Target hover design point was hover out of ground effect at sea level 95° F at design gross weight in the compound helicopter configuration.

Model testing in conjunction with moving base simulator studies and engineering analyses were used in the design phase. These tools will be used intermittently on an as-required basis to increase confidence for the flight test program and to assist in identifying design refinements. Laboratory and fatigue tests were conducted to verify the structural integrity and functional adequacy of the components and subsystems. A propulsion system test bed, capable of testing all dynamic components as an integrated system, was operated at load levels in excess of the predicted flight loads.

The XH-59A was first flown on 26 July 1973. The aircraft hovered and performed hover turns. Subsequent flight testing investigated rotor rpm changes from 103 percent to 88 percent, stick and pedal reversals, sideward and rearward flight to 10 knots, forward flight to approximately 30 knots, and longitudinal spike inputs. On 24 August 1973, the first flight model of the XH-59A crashed while tests were being conducted to investigate blade edgewise response at reduced rotor rpm. The pilot was attempting to trim the aircraft at 30 knots when the aircraft experienced a pitch-up divergence at approximately 28 knots. The aircraft settled to the ground tail first and was extensively damaged, but the pilots received only minor injuries. Following a detailed accident investigation, design changes were made to the flight control system. The ABC program was restructured and a new contract awarded in November 1974. The new contract calls for resumption of flight testing as a basic helicopter, with the modified flight control system installed and flight testing with jet engines installed for auxiliary propulsion. Ground tests, wind tunnel tests, and analytical studies will also be made to further investigate and substantiate the flight worthiness of the test aircraft. A unique feature of the new contract requires that pre-flight predictions of key aircraft parameters agree with actual flight data within specified tolerances. Where significant differences occur, flight testing will stop until the reasons for the difference is understood and the mathematical model revised to produce results in consonance with flight data.

On 21 July 1975, flight testing of the basic helicopter with the modified control system installed was begun. Low-speed (up to 80 knots) tests were conducted to verify the adequacy of the modified control system. Test results showed that the modified control system resolves the problem that caused the crash of the first ABC aircraft. Test results also showed good correlation with pre-flight analytical predictions for most parameters of interest. Subsequent to the low speed tests, the flight envelope for the basic helicopter was expanded during additional flight testing that was completed in March 1977. Flight results confirmed several important advantages of the concept and identified some shortcomings. As of the end of March 1977, the ABC rotor system had been flight-tested in a pure helicopter mode for 67 hr. The results of the flight tests in the pure helicopter mode were generally favorable and concept feasibility in this mode has been demonstrated. To date, the XH-59A has flown to speeds of 155 KTAS in level flight and 192 KTAS in a dive. Sustained maneuvers at 2.5 g were demonstrated at speeds from 80 to 150 knots and nearly 0 g was demonstrated at 80 knots. The handling qualities have generally been above average to excellent. Rotor behavior has been as predicted and the blade tip clearance has remained well above the minimum except during a rapid roll reversal where it reduced to the minimum 10 in. Rotor and control loads have been well below endurance levels in most flight conditions. Vibration levels without the passive isolators are acceptable to the pilot throughout the envelope except at 40 to 60 knots and at speeds beyond 120 knots. Because there is no tail rotor, the XH-59A is significantly quieter than are other helicopters at the same disc loading.

In June 1977, this program was restructured as a joint Army/Navy/NASA ABC Helicopter Technology Program. The purpose was to evaluate the concept at high speeds for comparison with other concepts by flight testing the XH-59A aircraft equipped with added auxiliary propulsion engines and by conducting additional large-scale research in ground-based facilities. The objectives of the XH-59A flight test with auxiliary propulsion is to demonstrate feasibility of the ABC concept to achieve high-speed flight up to 300 knots. The ground-based program will include wind tunnel tests of the XH-59A vehicle at the NASA/Ames Research Center to provide a correlatable wind tunnel and flight-data base, to provide a

basis for quantifying drag from the flight-test data, and to provide advanced technology data necessary for assessing the potential feasibility of mission-oriented ABC vehicles, including hub drag reduction and rotor/tail/propulsion system interference alleviation.

Based on successful flight and wind tunnel testing, several development programs to better exploit ABC rotor technology will be considered. These include:

- Development of ABC rotor blades made from high-modulus material
- Concurrent development of a lightweight rotor hub
- Rotor hub fairings for reducing hub drag
- Development of rotor/flight control systems
- Development of vibration reduction systems
- Rotor slowing and stopping

Rotor blades made of high-modulus material would be fabricated and subjected to a battery of structural tests. A lightweight rotor hub employing tension/torsion straps would be fabricated and tested in conjunction with the high-modulus rotor blades. Wind tunnel tests of full-scale rotating rotor hub fairings would be conducted. Rotor control and flight control systems, tailored to specific Army missions, would be designed, verified on a moving base simulator, and fabricated. Breadboard hardware would be flight tested. Vibration reduction systems would be designed and the leading concept fabricated and flight tested. A slowed/stopped rotor model would be designed, fabricated, and wind tunnel tested. Fabrication and full-scale tests of a slowed/stopped ABC rotor system would be conducted after efforts identified above have been completed. A convertible engine propulsion system capable of supplying power to provide both lift and thrust has been considered. An ABC aircraft equipped with a convertible engine propulsion system, is illustrated in figure AT–10. Open props would be replaced with fans, depending on the mission application.

ADVANCED TECHNOLOGY DEMONSTRATOR ENGINE PROGRAM – 800 SHP

GENERAL

Research and development programs conducted over the past ten years have demonstrated potentia improvements in engine performance through the application of advanced component technology and design concepts. Advanced technology such as higher compressor pressure ratios, improved combustor efficiency and temperature distribution, improved turbine cooling techniques, improvement in material properties, etc., conducted under basic and exploratory development (6.1 and 6.2 funded) efforts have provided a firm basis for proceeding with advanced development, demonstrator gas generator/engine programs. Two successful efforts that have used this "building block" philosophy were the 1500 hp Demonstrator Engine program and the Small Turbine Advanced Gas Generator program. The 1500 hp Demonstrator Engine program identified the capabilities and limitations of an engine in that size class and has since transitioned through full engineering development (T-700). The T-700 is the power plant for the Army's Utility Tactical Transport Aircraft System and Advanced Attack Helicopter aircraft programs. In reviewing the Army's future propulsion needs it has been determined that the greatest potential improvement in future aircraft systems can be realized through technology verification in an engine of approximately 800 hp. In recent years the need for improvements in engine technology has become more urgent, not only in the areas of vehicle flying performance, but also in areas of cost, reliability, maintainability, safety and survivability. The achievement of the goals for the 800 hp ATDE will provide an effective and viable means of meeting these requirements.

CONCEPT CHARACTERISTICS

In determining the performance objectives for the 800 hp ATDE, consideration was not only given to the achievable thermodynamic performance, but also to all other aspects of an engine in its operational environment. Any engine demonstration program will be most successful if the technology demonstrated is in the form of a complete engine with consideration for operational constraints, the environment in which such an engine would be required to operate (sand, dust, hot day, altitude, hostile action taken against the engine/aircraft, etc.), the maintenance system to be utilized, and any other outside influence which could compromise the actual technology demonstrated. Since various component configurations can be utilized to arrive at a given level of performance, it was decided that two separate approaches should be taken in the ATDE program. Competition between these two approaches will force both to be more

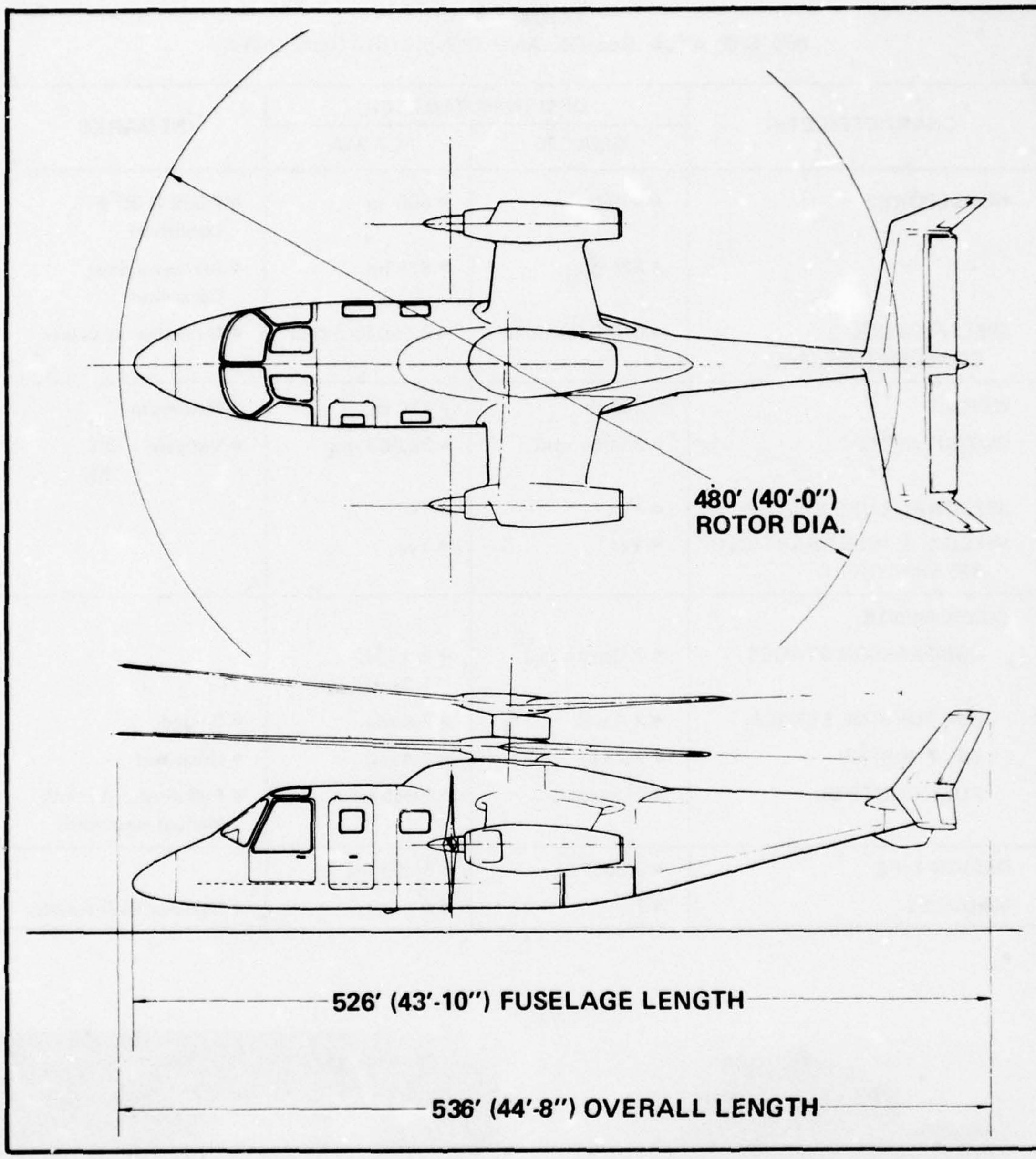


Figure AT–10. ABC aircraft equipped with a convertible engine propulsion system.

intensively developed than a sole source development – thus resulting in a better final product. Design and configuration data for the 800 shp ATDE's is shown in table AT–C. Figures AT–11 and AT–12 show a mock-up of each engine.

Figure AT–13 shows the improvements that could be realized in a new helicopter design using ATDE technology versus current engine technology. Over and above the performance improvements indicated, such an installation would be very attractive from a cost standpoint since savings in vehicle weight currently result in dollar savings of about $80/lb. Projected savings in consumables and airframe acquisition as influenced by improved engine performance is shown in figure AT–14. Improved maintenance characteristics, lower vulnerability and better reliability

TABLE AT–C
800 SHP ATDE DESIGN AND CONFIGURATION DATA

CHARACTERISTIC	DESIGN PARAMETER		REMARKS
	GMA 500	PLT 34A	
HORSEPOWER	• 600 hp	• 600 hp	• 4,000 ft 95°F Condition
	• 825 hp	• 825 hp	• Sea Level Std Condition
SPECIFIC FUEL CONSUMPTION (SFC)	• 0.550 lbs/hp-hr	• 0.550 lbs/hp-hr	• Maximum at Cruise
WEIGHT	• 220 lb	• 220 lb	• Maximum
OUTPUT SPEED	• 30,000 rpm	• 30,000 rpm	• Variable + 5% − 15%
INTEGRAL LUBE SYSTEM	• Yes	• Yes	
INTEGRAL INLET PARTICLE SEPARATOR	• Yes	• Yes	
COMPONENTS:			
COMPRESSOR STAGES	• 2 Centrifugal	• 2 Axial, 1 Centrifugal	
H.P. TURBINE STAGES	• 2 Axial	• 2 Axial	• Cooled
L.P. TURBINE	• 2 Axial	• 1 Axial	• Uncooled
FUEL CONTROL	• Electronic	• Electronic	• Full Authority with Manual Reversion
DESIGN LIFE	• 5,000 hrs	• 5,000 hrs	
MODULES	• 7	• 4	• Modular Maintenance

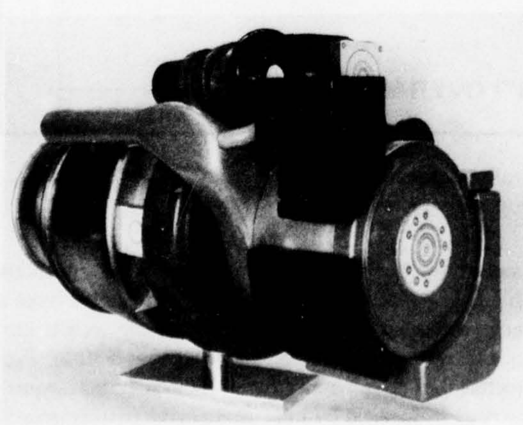


Figure AT–11. Allison GMA 500 engine mock-up.

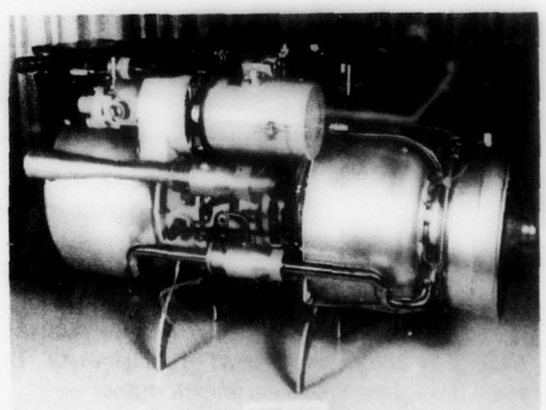
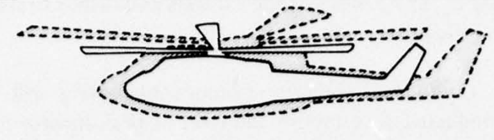


Figure AT–12. Lycoming PLT34A engine mock-up.



PARAMETER	800 SHP ATDE	CURRENT TECHNOLOGY	PERCENT IMPROVEMENT
•NUMBER OF ENGINES	2	2	–
•TOTAL SHP	1650	1800	8.3
•SHP PER ENGINE	825	900	8.3
•DESIGN GROSS WEIGHT (lbs)	7484	8807	15.0
•EMPTY WEIGHT (lbs)	4600	5527	16.8
•STRUCTURAL WEIGHT (lbs)	3643	4156	12.3
•MISSION FUEL (lbs)	947	1329	28.7
•DIAMETER (ft)	34.5	41.2	16.3
•LENGTH OF AIRCRAFT (ft)	42.0	49.1	14.5

Figure AT–13. Effect of engine technology on new helicopter design (2-hr mission).

CONDITIONS	SAVINGS
FUEL SAVINGS PER FLIGHT HOUR ASSUMING: 1000 AIRCRAFT FLEET 15 YEAR SERVICE LIFE 35 FLIGHT HOURS PER MONTH 50¢ PER GALLON $120 PER LB OF AIRFRAME WEIGHT	• 191 POUNDS (29.4 GALLONS)
FUEL SAVINGS ARE	• 1203.3 MILLION POUNDS (185.2 MILLION GALLONS) • 92.6 MILLION DOLLARS • CONSUMABLES (POL) COSTS REPRESENT 40% OF OPERATIONAL COSTS
AIRFRAME INVESTMENT SAVINGS ARE	• 61.6 MILLION DOLLARS (DUE TO LOWER EMPTY WEIGHT) • AIRFRAME COSTS REPRESENT 25% OF ACQUISITION COST

Figure AT–14. Effect of engine technology on aircraft (from engine weight and fuel savings only).

than current engines will all result in higher aircraft availability and further reduction in life cycle cost.

OBJECTIVES

The broad objectives of the ATDE program are to determine the achievable level of performance of a turboshaft engine in the 800 shp category and to minimize future development risk of such an engine.

Specific goals are to:

- Demonstrate improvements in specific fuel consumption of 17–20 percent and in specific horsepower of 25–35 percent as compared to current turboshaft engines in this power class (see figure AT–15).
- Demonstrate improved reliability, maintainability, and survivability characteristics.
- Quantify engine cost factors and identify areas where future development cost and acquisition cost savings can be made without compromising the engine's capability.

IMPLEMENTATION PLAN

GENERAL

The ATDE program, with contract awards to two propulsion system contractors, will provide two separate approaches to advanced technology turboshaft engines in the 800 shp class. The 48-month program was initiated in February 1977 and will consist of the design and analysis of the engines.

The ATDE will basically meet the design requirements of MIL-E-8593A with primary application to

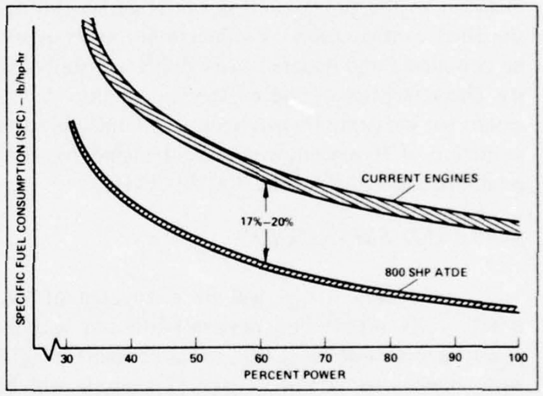


Figure AT–15. Fuel consumption vs percent power.

rotary-wing aircraft. Consideration is being given to rotor harmonic frequencies, shaft imbalances, and load system torsional responses that might be associated with a helicopter environment. In addition to the usual elements of design, particular emphasis will be placed on the design considerations discussed below.

DIAGNOSTICS AND CONDITION MONITORING

An investigation will be conducted resulting in an assessment and identification of specific diagnostic equipment and inspection techniques that will enable the engine to be maintained using a condition monitoring/on-condition maintenance philosophy.

RELIABILITY AND MAINTAINABILITY

A reliability analysis and review program will be established to ensure that maximum inherent reliability is built into all components of the engine. This

effort will be active from original layout through the full engine test phase.

A maintainability analysis and review program will be conducted to ensure the best engine design and component configuration from the standpoint of maintenance and other design requirements with consideration for the Army three-level maintenance system, personnel, tool requirements, etc. A maintainability teardown evaluation will be conducted on the final engine configuration during the latter part of the program.

BALLISTIC VULNERABILITY

Attention to the effects of ballistic threats will be included in the program from initial design through the final configuration. A vulnerability analysis will be conducted and updated to establish the vulnerability characteristics of the engine and to provide the means for initiating improvements. A vulnerable area reduction of 50 percent over current engines has been established as a goal for the 800 shp ATDE.

INFRARED SUPPRESSION

A preliminary design will be conducted of two types of IR suppression devices (with and without power turbine shielding) that could be made integral with engine rear frame. Trade-off analysis will be made for the two types of suppressors showing metal and plume radiation emission along with the attendant penalties (power loss, weight, size, etc.) as compared to a standard tail pipe.

ENGINE COST AND TRADE-OFF ANALYSIS

A continuing Design to Unit Production Cost (DTUPC) analysis will be conducted using a production cost goal. The total cost of ownership of the engine will be updated to reflect any change in design, materials, or fabrication techniques as the program progresses. Any techniques or methods of reducing cost which cannot be incorporated into the ATDE program will be identified and justified for possible inclusion in any subsequent development effort. This will afford the Army and industry a unique opportunity to address this important issue at a very early stage in the development cycle.

TEST PROGRAM

The test program will be composed of component tests, gas generator testing, full engine development testing, and a series of special tests and demonstration as follows:

Component Testing. Component testing will be conducted to establish the level of performance and increase design credibility prior to committing the individual components to inclusion in a gas generator test. The amount of testing will vary greatly depending on the level of experience with each particular component design. Any component design modifications required will be validated by component testing.

Gas Generator Testing. The primary purpose of gas generator testing is to determine the performance of the aerodynamic components, as well as some of the mechanical parts, in an engine environment. Tests will be made to check the interaction between components, effect of tip clearance, dynamic responses, etc.; that is, those investigations that can only be accomplished in an engine environment.

Full Engine Development Testing. In addition to further defining the performance obtained in gas generator tests, the power turbine, power shafting, lubrication system and fuel control system will be tested. Durability testing will be accomplished and some testing of the full engine will be done in preparation of those specific tests or demonstrations that will occur toward the end of the ATDE program. Approximately 500 hr of engine testing (total of gas generator and full engine testing) are planned.

Specific Tests and Demonstration.

- A sand ingestion test will be performed with a specified contaminant to determine the deterioration in performance or other critical wear.
- Exhaust emissions (including a smoke survey) will be measured over the power range of the engine.
- Tests will be run to determine the effect of rapid, asymmetrical, engine inlet air temperature rise.
- The specific fuel consumption at 480 shp and maximum power at both sea level and 4000 ft, 95° F will be determined.
- A 30-hr durability test will be run, consisting of numerous cyclic operations, with approximately half the time at full power. During this test the accessory pads and customer power pads will be loaded and cycles will be run with maximum bleed air being extracted.

INTRODUCTION

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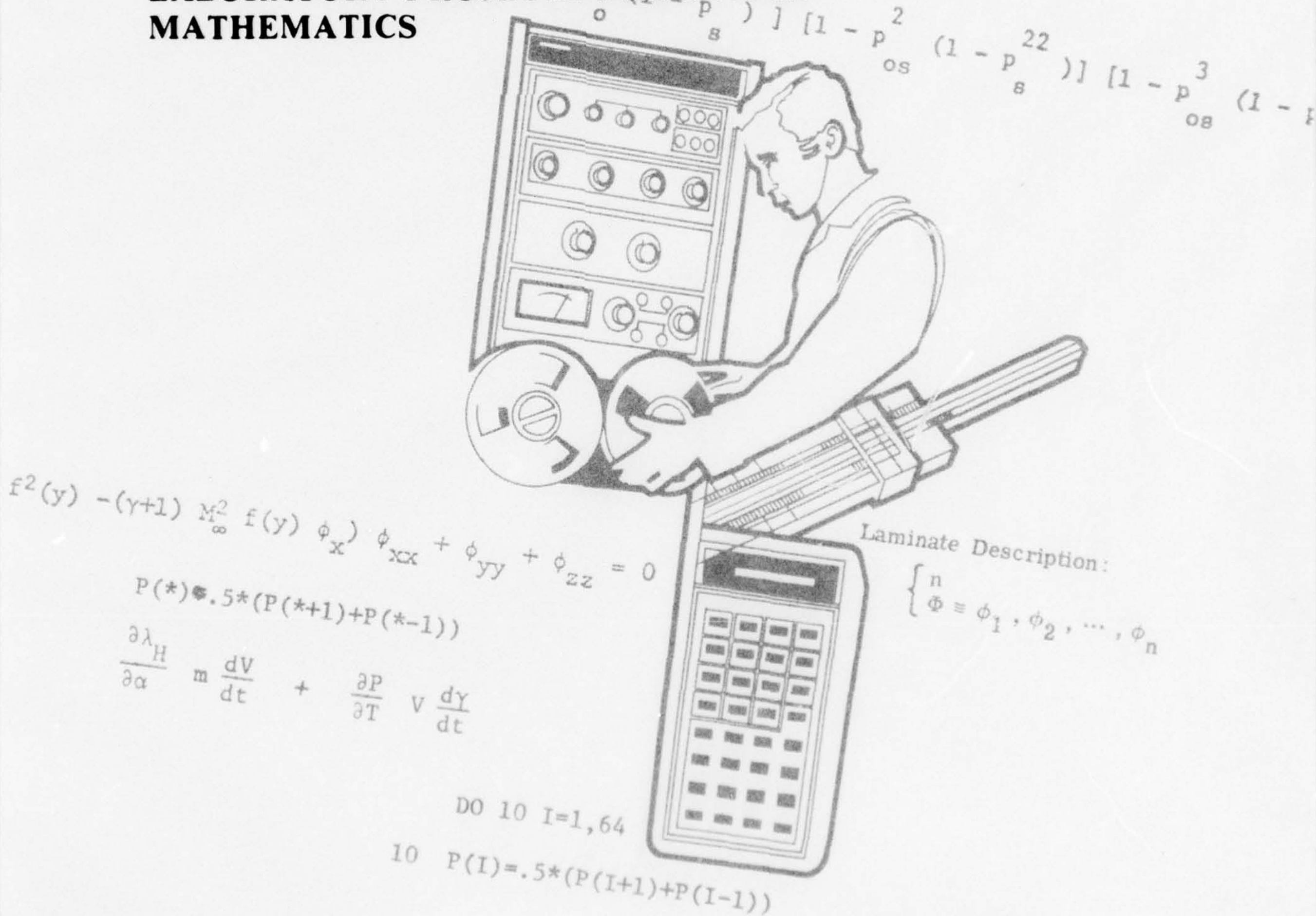
AREAS OF APPLICATION

SUBDISCIPLINES

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

LABORATORY PROJECTS FOR FY78 IN MATHEMATICS



INTRODUCTION

Mathematics has long played a central role in the intellectual and technological history of mankind. This statement hardly begins to convey the effect of mathematics on modern civilization, or to account for the dynamic application of mathematical sciences to other disciplines such as engineering, physical sciences, medicine, economics, and management.

The development of the physical sciences and the advancement of modern technology continue to use sophisticated mathematical techniques and concepts. The research efforts in this Plan indicate the needs of mathematics so as to enhance, facilitate, and strengthen theoretical, experimental, and numerical investigations. In particular, appropriate mathematical knowledge and computer science are indispensible to airmobile research, as well as to risk assessment. Mathematical concepts that are of particular importance include partial and ordinary differential equations, optimization theory, finite difference methods, finite element methods (including Rayliegh-Ritz-Galerkin techniques), boundary value problems, Bayes decision theory, and parameter identification. Also, in solving problems numerically, parallel processing has a profound influence on the computational capability. For instance, the computer ILLIAC IV is faster than the IBM 360/67 by a factor of about 200. Consequently, solutions to problems that are technically as well as economically infeasible with conventional computers can now be obtained. However, this unique capability cannot be realized by the sequential logic. In order to utilize such a computing structure efficiently, a prospective problem must be amenable to parallel, rather than sequential, processing. Consequently, basic and expository research in these areas, as well as parallel algorithmic efforts, constitutes a relevant component of the fundamental sciences in airmobile investigation.

TECHNOLOGICAL DISCUSSION

AREAS OF APPLICATION

Aerodynamics, structures, propulsion, and decision analysis constitute the basic domain to which much of the Laboratory's basic research efforts are devoted. The end results of these efforts contribute to fill the technological needs and requirements of advanced airmobile systems. From a mathematical point of view, these results provide technology for the following major areas of application:

- Design of systems, such as high-speed rotor design.
- Resource allocation, such as T-800 program source selection analysis.
- Performance effectiveness, such as optimal diagnostic procedure for malfunctioning system.
- Risk analysis for systems, such as rotor systems research aircraft application.

One of the missions of this Laboratory is to establish the requirements and to fill the voids of advanced airmobile systems. The unique behavior of the rotor draws much of the Laboratory's design efforts; for example, the design of an improved transonic tip configuration. Due to limited available resources, a significant problem is resource allocation, for if the distribution of resources is "proper," then it maximizes the chances of meeting the performance/mission requirements. Also, another problem that all R&D managers have to contend with is the uncertainty of program success associated with each management decision. Therefore, resource allocation and risk analysis are important because of their overall effect on the R&D efforts and, hence, on the Laboratory. Performance analysis enables engineers and scientists to determine the criteria under which a given system can be developed more efficiently.

SUBDISCIPLINES

Although the Laboratory research is quite diversified, in abstract mathematical setting the basic essential mathematical tools for airmobile research can be classified within four mathematical subdisciplines:

- Numerical analysis associated with differential equations and/or algebraic systems
- Mathematical programming
- Theory of linear and nonlinear operators
- Probability theory

On the basis of the above statement, it appears that these are the only relevant mathematical concepts for airmobile research. In essence, they encompass almost every field of mathematics. For instance, the ingredients for differential equations and numerical analysis are the classical real analysis and theory

of complex variables. These in turn, have the theory of set, theory of real and complex numbers, algebra, and Euclidean geometry as their building blocks in a finite dimensional setting.

In view of the Laboratory's applications, numerical analysis plays the central role in the Laboratory airmobile research; that role is substantiated by the following:

- Newtonian mechanics dictates that every dynamical system that obeys the classical laws of physics can be written in an equivalent mathematical equation.
- The end result of most numerical schemes applied to differential or integral equations gives rise to an algebraic system.
- Numerical approach provides an immediate means of obtaining an approximate solution to physical problems within a reasonable time frame.

It is well known that the computational aspects of practical mathematical programming present some problems for a present-generation computer. In particular, in dynamic programming if the amount of resources is large and the increment is small, a tremendous amount of memory (including temporary), as well as the number of arithmetic operations, is required.

Although the numerical approach in obtaining an approximate solution to a given problem has its own advantages, there are some difficulties associated with computational physics. An obvious disadvantage of numerical solution is its discrete form, to which only a limited number of analytical studies can be made. On the other hand, the analytical approach toward the solution would eliminate computational problems and preserve the intrinsic analytical properties of the solution. Therefore, an analytical result is desirable for further studies, such as the sensitivity of the parameters involved and their ranges of validity.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and system elements are presented in the Technology Introduction section of the Plan. This section applies that process to the mathematical science discipline for the near-term time frame. The OPR is not an objective of the Plan, but is provided to show the procedure used by the Laboratory in the selection of programs within a discipline as constrained by the Army aviation R&D budget.

OBJECTIVES

The near-term program objectives of the various subdisciplines within the mathematical science discipline can be established as follows:

- To overcome computational barriers of CPU time, cost, and storage limitations imposed by conventional computers, by research on computational techniques with applications to airmobile research efforts, such as high speed rotor design.
- To enhance computational capability on resource allocation by investigating the suitability of dynamic programming through parallel processing.
- To exploit the generic properties of a mathematical structure associated with logic modeling concepts for maintenance analysis.
- To research analytical methods, preserving the intrinsic analytical properties possessed by closed form solutions in solving airmobile problems such as structural dynamics of a rotor.
- To perform mathematical analysis on performance effectiveness such as direct operation cost modeling of air vehicles.
- To strengthen the capability in risk analysis and maintenance analysis through exploitation of probability theory and establishment of mathematical foundation.

PROGRAM PRIORITIES

General. Table MA–A presents, in a prioritized listing, the mathematical science technology subdisciplines, technical developments, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts that support the near-term technical objectives.

TABLE MA–A
PRIORITIZED MATHEMATICAL SCIENCE OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	TECHNICAL DEVELOPMENTS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Numerical analysis associated with differential equations and/or algebraic systems	I	• Algorithms for both direct and iterative methods	I	• Optimality	I
				• Life cycle cost	II
		• Resource allocation algorithms	II	• Airmobile system design	III
• Mathematical programming	II	• Optimal fault-isolation technique	III		
• Theory of linear and nonlinear operators	III	• Analytical approach	IV		
• Probability theory	IV	• Risk analysis schemes	V		

Technology Subdisciplines. The mathematical science technology subdisciplines are represented by the following major topical areas:

- *Numerical analysis* – a branch of mathematics whose theory underlies the development of numerical computation process for obtaining, in general, an approximate solution to a mathematical expression.

- *Mathematical programming* – a branch of applied mathematics that can be further partitioned into sub-branches, based on the given cost function and its associated constraints, such as integer programming, linear programming, nonlinear programming, and dynamic programming. The latter deals with a multistage decision process. Solution of a mathematical programming problem is that solution or those solutions which maximize (or minimize) the cost function.

- *Theory of linear and nonlinear operators* – addresses the intrinsic properties, determined by deductive reasoning, that pertain to a function or transformation. The operator notion implies that the domain as well as the range of a transformation need not be the real numbers and is generally a vector space. An operator for which the distributive law holds is called a linear operator. For example, an m by n matrix is a linear operator whose domain is an nth dimensional vector space and whose range is a vector space of dimension m. Similarly, a differential equation governing the behavior of a rotating helicopter blade defines an operator having the set of all possible responses (solutions) as its domain and the loading (forcing functions) belonging to the range.

- *Probability theory* – a theoretic treatment of observable events occurring in connection with non-deterministic phenomena.

Technical Developments. The technical developments identified in table MA–A are the relevant mathematical procedures developed for the implementation of the mathematical science objectives and goals.

System Effectiveness. In the area of system effectiveness, the primary influence of mathematical science is the optimal realization attained through the technical developments and the objective determination of life cycle cost and improved airmobile system design, in support of the Laboratory's research efforts.

Priorities. With reference to table MA–A, the mathematical science subdisciplines, technical developments, and system effectiveness criteria are presented and ordered by priority – roman numeral I, representing the highest priority.

MAJOR PROGRAM THRUSTS/RATIONALE

The OPR procedure described above was used as an aid in the development of the FY78 program elements for the mathematical science R&D effort. These elements were aligned with Command Guidance funding and STOG-78 requirements to form the FY78 mathematical science technology development program.

The first priority major thrust is to develop mathematically valid and practically useful mathematical techniques for the attainment of optimality, life cycle cost, and improved airmobile system design through exploitation of and research on the above listed subdisciplines. Laboratory research effort strongly supports this thrust. For example, in aerodynamics research, the end result of most numerical schemes applied to differential or integral equations gives rise to a large algebraic system. Closed form solution to this type of problem is usually impractical if not impossible. So one seeks an approximate solution to the problem utilizing the capability of present-generation high-speed computers. Then the problem is to develop and exploit an efficient iterative method that is compatible with the given computing structure.

The second priority major thrust is to establish mathematical structure, for existing as well as conceptual airmobile systems, and to deduce from the model those generic properties contained within the system. For example, a task under the Laboratory's reliability and maintainability investigatory efforts was to establish the feasibility of logic modeling concepts for maintenance analysis. This modeling concept is an engineering innovation. A mathematical structure of a logic model for a physical system was established and from it some useful generic properties were obtained, leading to an optimal diagnostic strategy.

LABORATORY PROJECTS FOR FY78 IN MATHEMATICS

INTRODUCTION

The research program in mathematical science is at the (6.1) research level to increase mathematical knowledge and to strengthen R&D capability.

DESCRIPTION OF PROJECTS

Project 1L161101AH45-TA IV is a research effort conducted to exploit and apply state-of-the-art mathematics in support of Laboratory research efforts, to develop a technology base in numerical analysis and computation techniques associated with processors with high-speed computation capabilities (e.g., CDC 7600 and ILLIAC IV computers at Ames), and to advance mathematics in areas applicable to airmobile R&D. The efforts under this project are directed toward the development and exploitation of numerical schemes for solving numerically transonic flow problems, as well as the investigation of the applicability of the theory of fuzzy sets to decision risk analysis and to the establishment of the optimal-fault isolation techniques for maintenance analysis.

FY78 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the mathematical science R&D efforts as presented in the technical discussion are shown and discussed in the Resources Required section. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.1 mathematical science FY78 R&D effort is $80,000 and represents 1% of the Laboratory's 6.1 R&D funds.

AIRCRAFT SYSTEMS
SYNTHESIS

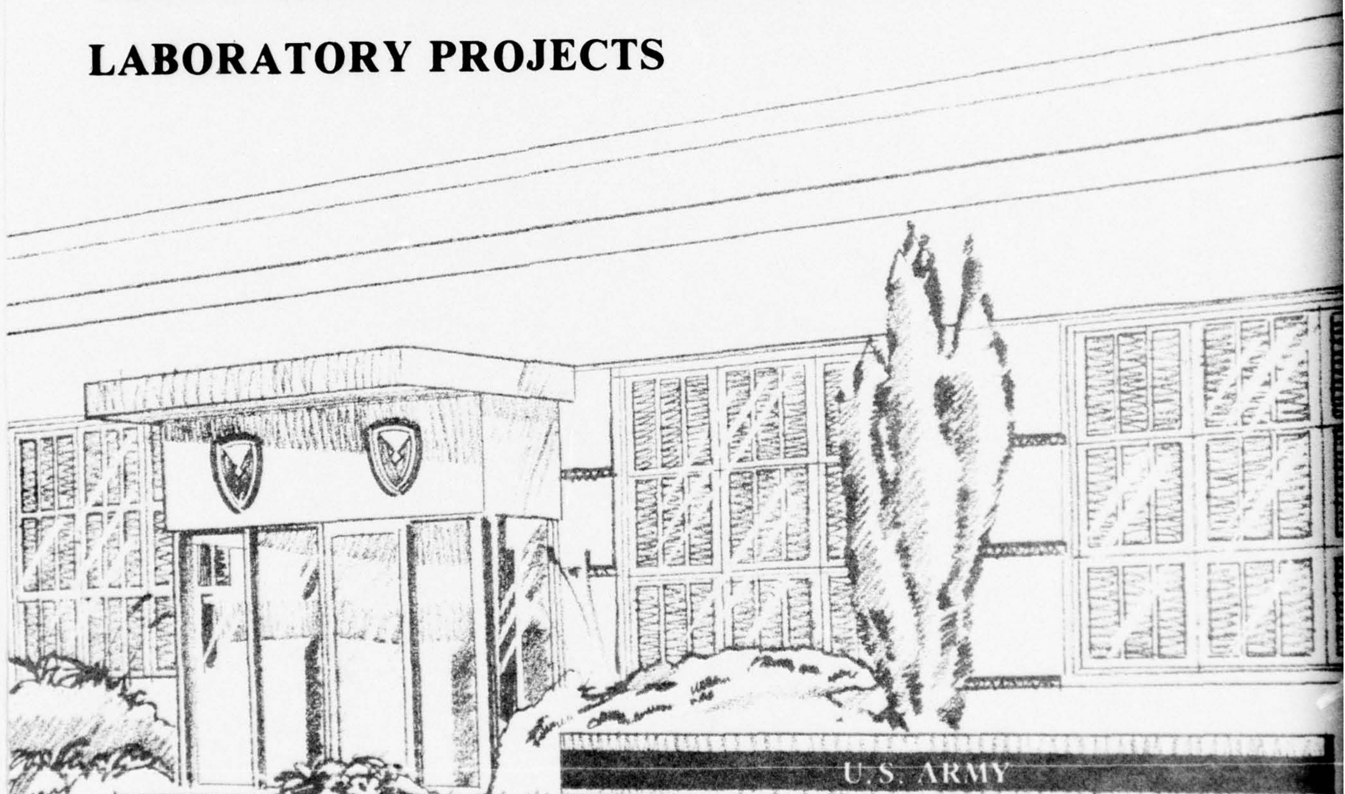
INTRODUCTION

MANAGEMENT

PRIMARY PROJECT MISSION

COLLATERAL MISSION RESPONSIBILITIES

LABORATORY PROJECTS



INTRODUCTION

The superiority of future Army airmobile systems depends on the availability and exploitation of new scientific knowledge. The development of an appropriate technology base to meet projected requirements can be ensured by formulating a time-phased prediction of technical potential set forth in an orderly sequence of coordinated R&D activities in the many disciplines and technologies required to develop airmobile systems. All the previous sections deal with airmobile systems and technologies. This section addresses the process that interrelates all the previous sections and results in an R&D program that provides the technology for current and future systems.

MANAGEMENT

The U.S. Army Research and Technology Laboratories is the aviation systems research laboratory of the U.S. Army Aviation Research and Development Command and is primarily involved in research, exploratory development, and advanced development through demonstration of technology. The Research and Technology Laboratories are the means by which AVRADCOM maintains a strong, relevant technology base for new development and improvement of airmobile systems.

Program management of the Aircraft Systems Synthesis Project is the responsibility of the Advanced Systems Research Office (ASRO) of the Research and Technology Laboratories Headquarters, located at Moffett Field, California. The Advanced Systems Research Office includes 18 professional staff positions, each responsible for one or more of the respective technologies or disciplines addressed in the technology section of the Plan as well as the Laboratories preliminary design group.

PRIMARY PROJECT MISSION

As indicated in the introduction of this section, the primary mission of the Aircraft System Synthesis Project is the development of an appropriate Army aviation R&D program. The process whereby this mission is accomplished is presented in figure SY–1. Each "step" enclosed by solid lines represents a major task assignment to ASRO.

The process begins with the analysis of Army aviation systems requirements. This is accomplished by individual members of the ASRO staff who have been assigned the responsibility to interface with a particular TRADOC proponent school or project manager. This activity can result from an official Required Operational Capability; from pre-ROC dialogue with TRADOC schools; from LOAs; from the

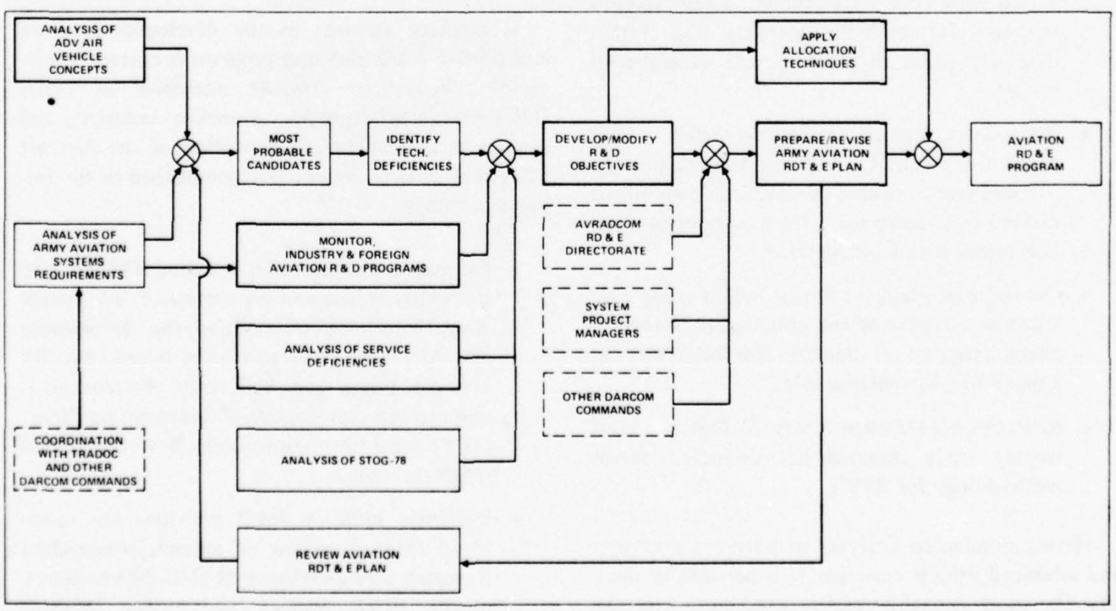


Figure SY–1. Aircraft systems synthesis process.

emergence of a new technical capability; or from the requirement for product improvement. In any case, this analysis activity is coordinated with TRADOC and other appropriate DARCOM commands.

Having addressed the subject of requirements, the next task in the process involves an analysis of advanced air vehicle concepts to develop candidates that satisfy the requirements. This activity requires the conduct of preliminary systems design engineering (PSDE), in which vehicle and subsystem performance are "traded off" against life cycle costs. Credible PSDE output requires validated methodology; thus, an important ingredient in this activity is the development and maintenance of vehicle weight, performance, and life cycle cost models. As indicated in previous sections, PSDE activities may range in scope over all of the system life cycle and may be initiated for various purposes during any phase of the life cycle. To illustrate this point, recent analyses employing PSDE include the following systems:

- *Advanced Scout Helicopter* – This activity developed some 200 systems and subsystem configurations for purposes of performance/life cycle cost trade-off analysis.
- *Helicopter Commonality Feasibility Study* – This effort provided technical support and guidance to an evaluation of the feasibility of interservice helicopter commonality. Five basic helicopter types and numerous design missions within each type were studied. These systems represent future equipment at a stage earlier than any phase of the life cycle management model.
- *Advanced Composite Helicopter Study* – This study divided the UTTAS into five major components and compared the costs and benefits of making each component from composite materials rather than from metal.
- *Ducted Fan Platform Study* – This study provided an estimate of the potential performance characteristics of ducted fan platforms as applied to a surveillance role.
- *RPV Propeller Design Study* – This is a continuing study directed at developing design methodology for RPV's.

Having conducted analyses of both requirements and advanced vehicle concepts, it is possible to identify the most probable vehicle candidates and the technical deficiencies associated with each candidate. Examples of such deficiencies from early PSDE activities are:

- Lack of advanced engine technology to provide a small, low-cost engine in the 5–50 hp range.
- Undefined handling qualities requirements for low level night operations and nap of the earth flying as applied to the AAH and ASH.
- Undefined maneuverability requirements for UTTAS.

Such technical deficiencies, when identified, are reviewed for possible inclusion in the aviation R&D program planning.

Another source of technical deficiencies which may affect the aviation R&D program planning is the operating fleet. Service deficiencies are monitored by various elements of the Laboratories and reflected in the R&D activity where appropriate. Examples of this type of service-generated input are:

- Tail boom structural/dynamics problems
- Engine compressor, turbine disk, and turbine blade problems
- Main rotor adhesive bond difficulties
- Excessive IR signature
- Bearing and seal problems

A primary element in the development of an appropriate R&D plan and program is current intelligence regarding similar activities in other U.S. Government agencies, domestic industry, and foreign establishments. This portion of the Aircraft System Synthesis Project is accomplished in the following manner:

- Current knowledge of the related R&D activity in NASA is ensured by means of the unique Army/NASA agreement, and the Aeronautics and Astronautics Coordinating Board (AACB). U.S. Air Force and U.S. Navy interchange is ensured through Technical Coordinating Papers (TCP) and Joint Commander's Technical Group (JCTG) activities.
- Domestic industry R&D activities are monitored through review of annual Independent Research and Development (IR&D) brochures, on-site IR&D reviews, and *ad hoc* industry briefings.

- Foreign technology, state of the art and military threat capabilities, are closely followed by the Foreign Intelligence Office. This position, located in the Laboratories Advanced Systems Research Office, takes cognizance of foreign efforts in areas and disciplines affecting Army airmobile capability and integrates the information obtained into the Army's aviation R&D program. This office utilizes Army, Department of Defense, and national intelligence sources to accomplish its mission.

At this point in the process, the Army Aviation RDT&E Plan preparation is initiated. Inputs are selected from AVRADCOM's D&E Directorate, system project managers, and other DARCOM major subordinate commands. These inputs are reviewed and combined with the deficiencies identified above, and the R&D near- and long-term objectives are developed or modified (these objectives are presented for each of the respective disciplines in the technology section of this Plan). The Plan is then completed and distributed internally, and to industry on request. Since the technology requirements and the threat are dynamic, the Plan is updated annually and thus, the process is continuous in nature.

The RDT&E Plan is a comprehensive guide to all promising alternatives for generating required airmobile system capabilities. It is not a specific R&D program. Development of the aviation R&D program evolves from the near-term objectives of the Plan after the constraints imposed by the budget, available personnel, and facilities have been considered. This process is referred to as resource allocation and requires some type of rational project selection process, whether it is quantitative or qualitative. Several attempts to develop a quantitative technique have been made, with limited success. The current procedure is qualitative in nature and involves participation of each ASRO technical specialist, and the senior management team of the Research and Technology Laboratories. The current resource allocation technique requires a clear definition of near-term R&D Directorate's objectives, priority of objectives and a rationale supporting the priority (OPR). These OPRs are prepared by the appropriate ASRO member for each technical discipline and are utilized by the Laboratories senior management to allocate resources and thus, structure the R&D program. (See OPR procedure in the Technology Introduction section.)

In the technology section of the Plan, each technical discipline is subdivided into a set of subdisciplines, and the near-term technical objectives are presented. It is clear that there is an interdependency between objectives, technical subdisciplines, vehicle subsystems, and eventual system cost effectiveness. Ideally, resource allocation could be quantitatively related to incurred cost (through subsystems) and to effectiveness (through subsystems) and the respective quotient minimized. In lieu of the quantitative ideal, priorities of technological major thrusts to be represented in the R&D program are developed.

COLLATERAL MISSION RESPONSIBILITIES

In addition to the primary mission described in the previous section, the Aircraft Systems Synthesis Project has additional collateral responsibilities, some continuous in nature, others of an *ad hoc* nature. These additional responsibilities complement the primary mission in all cases, and are discussed in the following paragraphs.

Unsolicited proposals, from industry and academic institutions, regarding airmobile technology, are submitted directly to the Research and Technology Laboratories for consideration in the overall R&D program planning. Furthermore, unsolicited proposals are also submitted from the Army Research Office (ARO), for evaluation and possible funding by that organization. The Advanced Systems Research Office is responsible for processing all such proposals, either reviewing or selecting other laboratory elements to review them. This activity involves approximately 210 proposals a year, with 50 percent of these being submitted by ARO.

Project manager support is both a continuing and *ad hoc* activity in the Aircraft Systems Synthesis Project. PM support from ASRO is provided as required, with frequent contributions to such projects as the T-700, AH-1Q, ASH, and UH-1/AH-1 Projects.

The Research and Technology Laboratories are chartered by Commander, DARCOM and AVRADCOM, to perform technical risk assessments of major programs on request. The Aircraft System Synthesis Project provides for such analyses. Recent technical risk assessments have been conducted on the following programs:

- Improved Main Rotor Blade
- Aquila RPV
- Rotor System Research Aircraft
- OH-58 Rotor Mast Failure
- OH-58 Mast-Mounted Sight

In addition to the above responsibilities, ASRO initiates special technical projects that are directed at R&D program or methodology improvements. The near-term goals of these projects are as follows:

- Research a high-output, lightweight, low-cost engine for aircraft and RPVs.
- Develop analytical treatment of a Life Cycle Cost (LCC) model.
- Initiate R&D Directorate Man-Machine Integration Research Program.
- Develop Logic Model Testing concepts as a design evaluation and maintenance troubleshooting tool for aircraft systems.
- Refine probablistic techniques for risk assessments and develop alternative methods for distinguishing between alternatives for source selections.

LABORATORY PROJECTS

INTRODUCTION

The Aircraft Systems Synthesis project has as its objective, the generation of a unified, coordinated research and development program responsive to Army aviation system requirements and major science and technology objectives. This work is accomplished by the Advanced Systems Research Office.

DESCRIPTION OF PROJECT

Project IL262209AH76–TA VII is an exploratory development effort with four major areas of effort as described below:

- Evaluate advanced air vehicle and subsystem concepts for official Army requirements; in-house computerized aircraft design capability will be expanded to improve accuracy, increase applicability to additional aircraft concepts, cover additional mission and performance requirements, and permit determination of additional off-design capabilities.
- Analyze Army aviation R&D programs. Continue the development of risk analysis methodologies and the conduct of technical risk assessments. Participate in program risk assessments, design reviews, and evaluation of technical plans and problems. Conduct analyses of proposed aircraft and weapons applications.
- Orderly planning and programming of Army aviation R&D.
- Provide a focal point for airmobile expertise and provide U.S. Army representation to industry for R&D activities (e.g., industry proposals, IR&D direction, etc.) with particular emphasis on technology transfusion.

FY78 FUNDS DISTRIBUTION

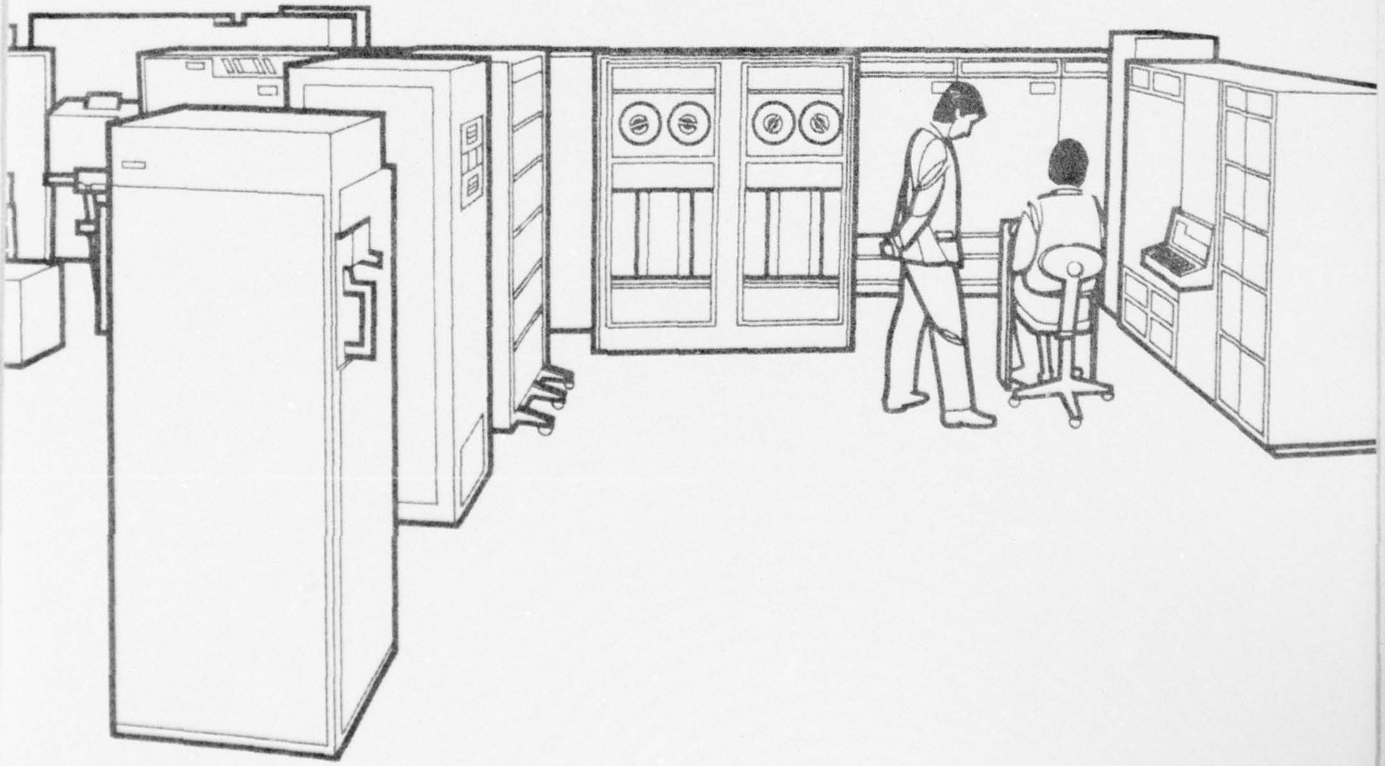
The resources that would be required to pursue the objective of the aircraft systems synthesis R&D efforts as presented in the technical discussion are shown and discussed in the Resources Required section. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 aircraft systems synthesis FY78 R&D effort is $1.01 million and represents 7 percent of the Research and Technology Laboratories' 6.2 funds (excluding Project 1L262201DH96 Aircraft Weapons Technology funds).

INTRODUCTION

SCIENTIFIC RESEARCH

FUNDAMENTAL SCIENTIFIC RESEARCH

BASIC SCIENCES



INTRODUCTION

The activities in the area of research (6.1) addressed thus far in this Plan have been directed toward specific technological objectives even though they are not necessarily associated with the development of one particular aircraft system. However, fundamental relevant research in physical, mathematical, environmental, and life sciences is also needed to add to the total knowledge from which new military air mobility capabilities are derived. Research activities in those scientific areas that are basic to air vehicle technology generally originate with the worker at the "bench level." Research and management need the resources, responsibility, authority, and flexibility to permit the researchers to explore at least the more promising of these technological opportunities in limited scope, even though there might be no obvious application or established potential payoff.

SCIENTIFIC RESEARCH

FUNDAMENTAL SCIENTIFIC RESEARCH

Fundamental scientific research constitutes a prerequisite to the development and improvement of Army aircraft systems. It is necessary for the formulation of new and improved concepts and provides direct and indirect fallout in all the technology areas identified in this Plan. Fundamental scientific research must be performed concurrently with technological investigations to establish, refine, and advance the state of the art of air vehicle technologies. The establishment of fundamental principles and data in all physical sciences provides the basis for advances in all air mobile system efforts.

The fundamental research programs at the AVRADCOM are pursued only within those scientific areas that relate to present and planned programs and needs.

Basic research in aerodynamics, structures, propulsion, and human factors has essential application to airmobility and aeronautical technology elements. Without this effort toward development of the technology base, only marginal increases in Army aircraft performance, stability, and control can be achieved. Research in these fundamental sciences must be continued to maintain Army competence and contact with emerging significant ideas and potential advances of science; to enable recognition of scientific and technological opportunities; and to provide an essential feeder line to exploratory development.

BASIC SCIENCES

The range of basic sciences that is applicable to and that supports Army Aviation technology is very broad, encompassing the entire scope of physical and life sciences. Most of the areas of the applicable physical sciences are outlined in the Military Themes documents of the Army Research Office. The primary Research and Technology Laboratories' effort in fundamental science is discussed below.

LASER VELOCIMETER TECHNOLOGY

Rotary wing fluid mechanics technology is severely limited by current techniques for theoretical prediction, or experimental measurement, of the fluid state in the vicinity of the rotor. The object of this project is to provide army scientists and engineers an additional opportunity to maintain and increase their competence by doing original work in areas suiting their talents, thereby promoting a vigorous internal research program of the highest caliber. The unsteady turbulent boundary layer on two-dimensional oscillating airfoils has been shown to contain the essential features of the rotor dynamic stall process which is the primary source of helicopter torsional rotor vibratory loads and a major source of the vertical and horizontal components of rotor hub forces and blade stresses. The laser velocimeter technology provides a unique opportunity to determine the sequence of events in the unsteady dynamic stall process, and then the opportunity to evaluate modifications designed to delay or soften the stall process. This capability can then be used to verify theoretical studies which define methods for reducing acoustic detectability, provide improved performance and improve the technological base for rotary-wing aerodynamics.

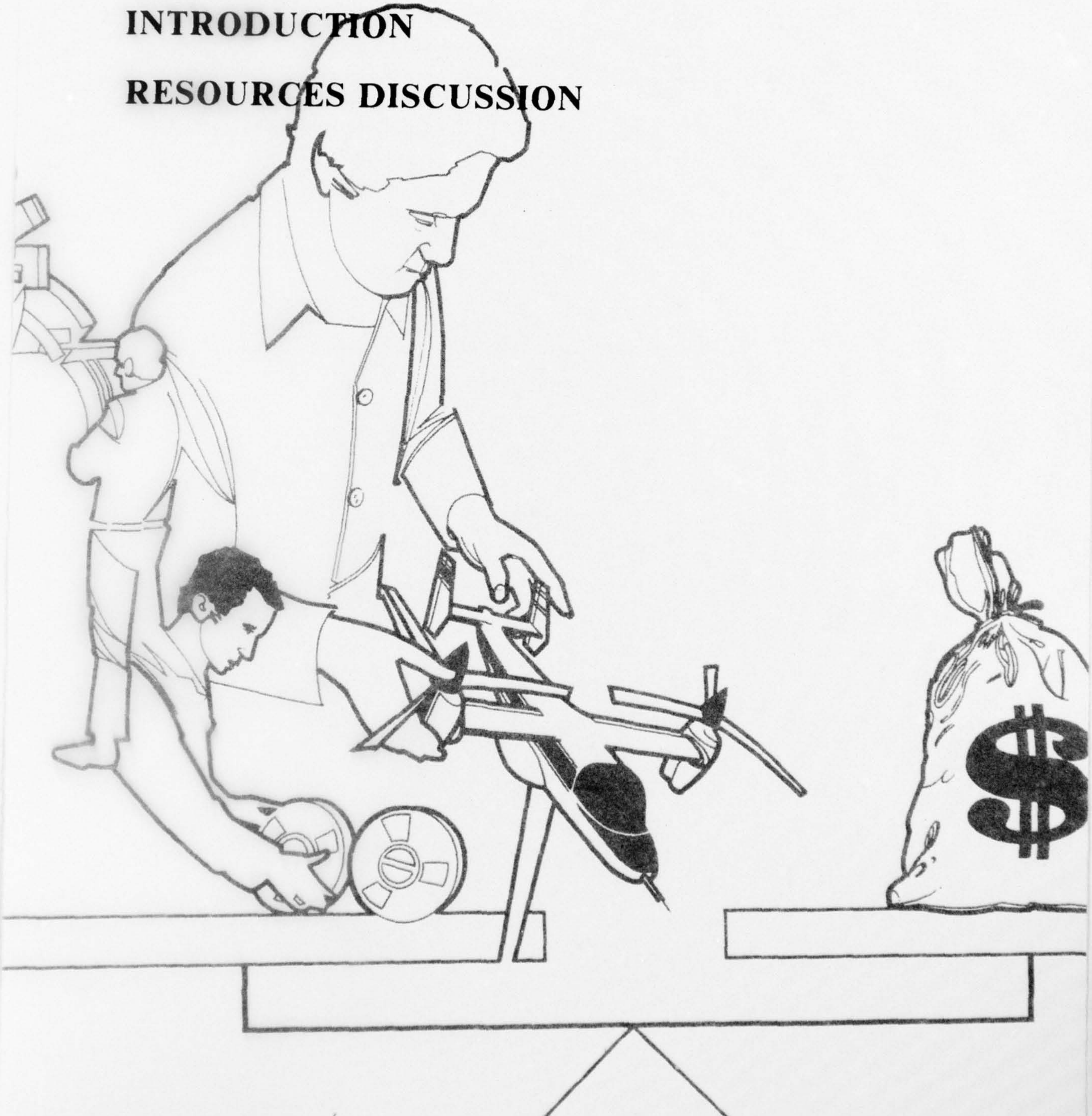
The concept of developing a test system that would allow both performance and acoustic experimental measurements to be made simultaneously has been evaluated by small scale experiments. The hover performance/acoustic test chamber and the rotor drive system, with a six-component balance, have been completed. Rotor strobed laser velocimeters have been tested and the laser anemometry equipment has been upgraded. The first wind tunnel tests

have proved that the laser technique has the capability to measure the vortex velocity components immediately ahead of and behind the rotor blade.

During FY77 the laser velocimeter equipment was upgraded and tests made to determine the effect of blade passage on the trailing vortex from a preceding blade passage, the effect of vortex passage on the blade, and the effects of blade-vortex interaction on near-field radiated noise. This experimental data will provide a valuable design guide for the rotary wing manufacturing industry.

INTRODUCTION

RESOURCES DISCUSSION



INTRODUCTION

The Army Aviation RDT&E Plan presents a time-phased analysis of the scientific and technological programs required to support the development of advanced airmobile systems. A plan becomes a program only when the required resources in terms of funds, facilities, and personnel are provided for its implementation.

This section estimates the total resources, in terms of funds and personnel, needed to advance the state of the art of the technologies and to develop airmobile materiel and systems. The estimates are primarily Army Aviation R&D Command resources. Manpower requirements are based on professional and technical personnel, excluding clerical-type personnel. These estimates constitute a very large requirement, as they represent the commitments desired to achieve all of the technological objectives described in the preceding sections of this Plan. Included in the estimates are the resources needed for the development of aircraft systems that are project managed. Funds for aircraft weaponization programs are controlled by AVRADCOM, although the work is primarily accomplished by Army Armament R&D Command, Army Missile R&D Command, and Ballistics Research Laboratory. Aviation electronics resources are directly controlled by Army Electronics R&D Command, although programs pertaining to airmobile systems are formally coordinated with AVRADCOM. The aviation electronics resources are not reflected in the resource charts presented in this section.

Even if unlimited resources were available, it is not likely that all the efforts would be pursued and all the goals achieved. Therefore, an estimate of resource requirements that was based on developing all of the concepts of each of the projected systems would be unrealistic. Moreover, the available options and alternatives to perform a given task diminish rapidly with time, so estimates of resource requirements are valid only on a relatively short-term basis.

Even more to the point, however, is the fact that there are never enough resources to undertake all of the research projects that optimum planning would indicate. There are generally many more feasible technical alternatives available to solve a particular problem than can be economically supported. The problem is to decide which efforts are to be supported and which goals can be achieved with the limited resources available. Compromises must be made among the myriad alternatives to maximize return on the investment. The stakes are too high to entrust the allocation of resources to top-of-the-head or arbitrary decisions. As a consequence of the broad scope and the complexity of this Plan, many factors must be considered if an effective decision is to be made. One decision can affect the operation of many efforts. Numerous efforts are interrelated; therefore, choices must be made with regard to the total effect considering the resources required, the objectives of each effort, and the effect of technological interchange between efforts. Recognizing the need for a rational, systematic resource allocation scheme, the Research and Technology Laboratories have developed a Laboratory Project Selection Process to assist Laboratory Management in program/resource allocation (see Technology Introduction section).

RESOURCES DISCUSSION

For reference purposes, figure RR–1 is a summary of funds per current command schedule in terms of funding categories and PM requirements. It is noted that project managed funds are excluded from the 6.3 and 6.4 funding categories and are included in the PM category, even though they are 6.3 and 6.4 type of funds. The PM category consists of UTTAS, AAH, Cobra, RPV, ASE, CH-47, SEMA, and NAVCON. The 6.4 funds in the figure may seem disproportionately small, but it must be understood that the majority of AVRADCOM 6.4 funds are project managed. Therefore, the 6.4 funds shown represent mainly developments of aircraft weaponization, cargo handling equipment, and ground support equipment.

Figures RR–2, 3, 4, and 5 show resources required by AVRADCOM and PMs to implement the technological objectives and to develop future systems. Resources are exhibited in terms of funds and AVRADCOM/PM manpower requirements. Only professional manpower requirements are shown.

Figure RR–4 shows minimal manpower in the 6.4 category, as the majority of 6.4 manpower is in PM support rather than in technology development work.

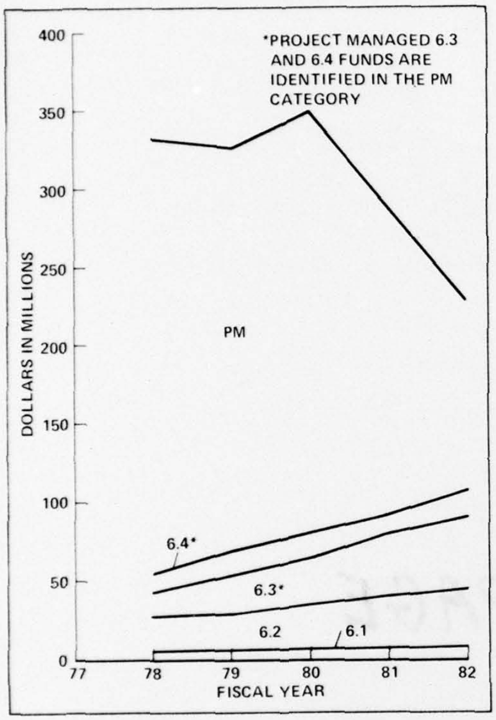


Figure RR–1. Distributions of funds by funding category and PM requirements.

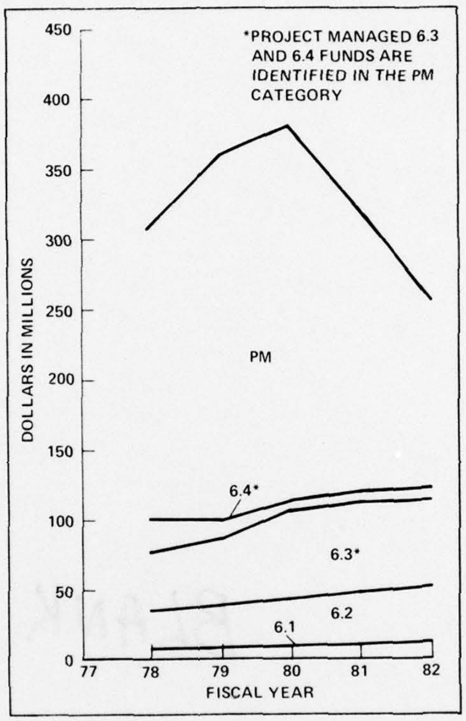


Figure RR–2. Distribution of required funds by funding category and PM systems.

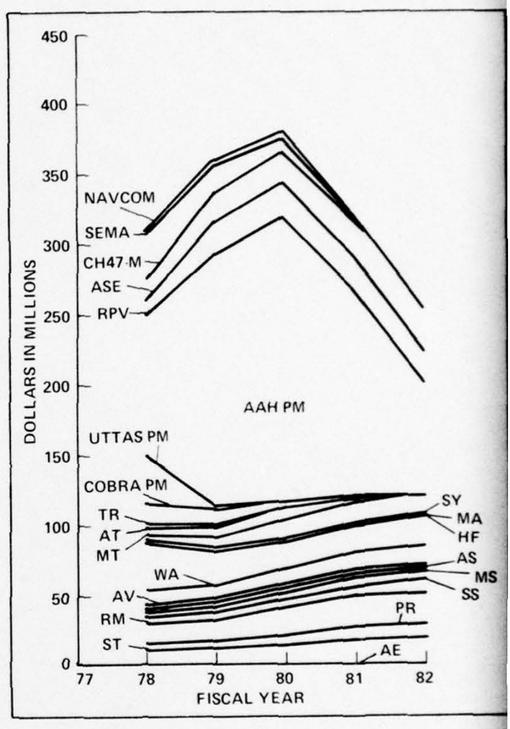


Figure RR–3. Distribution of required funds by technology and PM systems.

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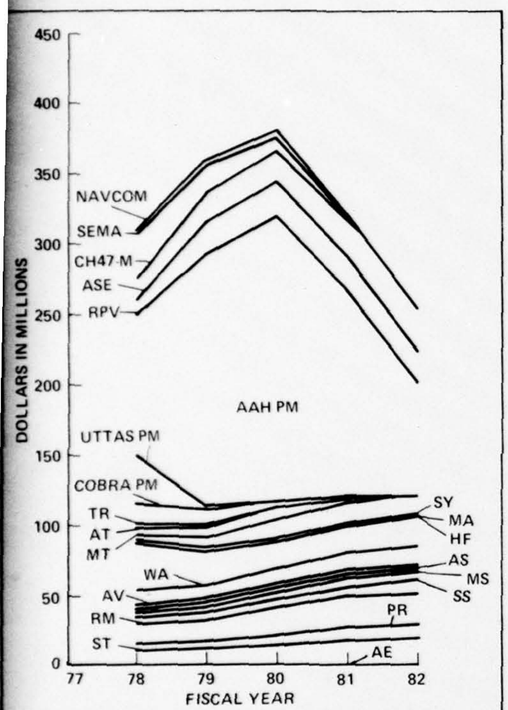


Figure RR–3. Distribution of required funds by technology and PM systems.

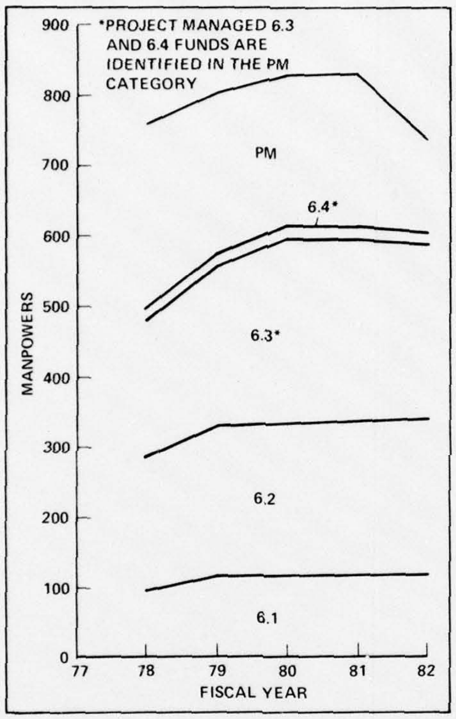


Figure RR–4. Distribution of required manpower by funding category and PM systems.

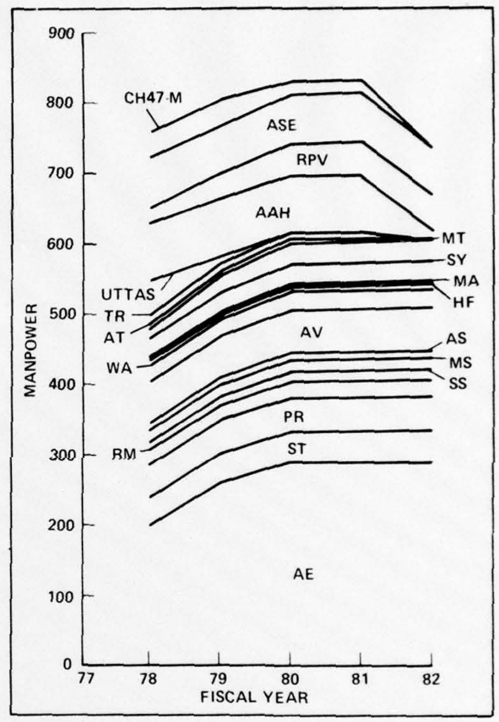
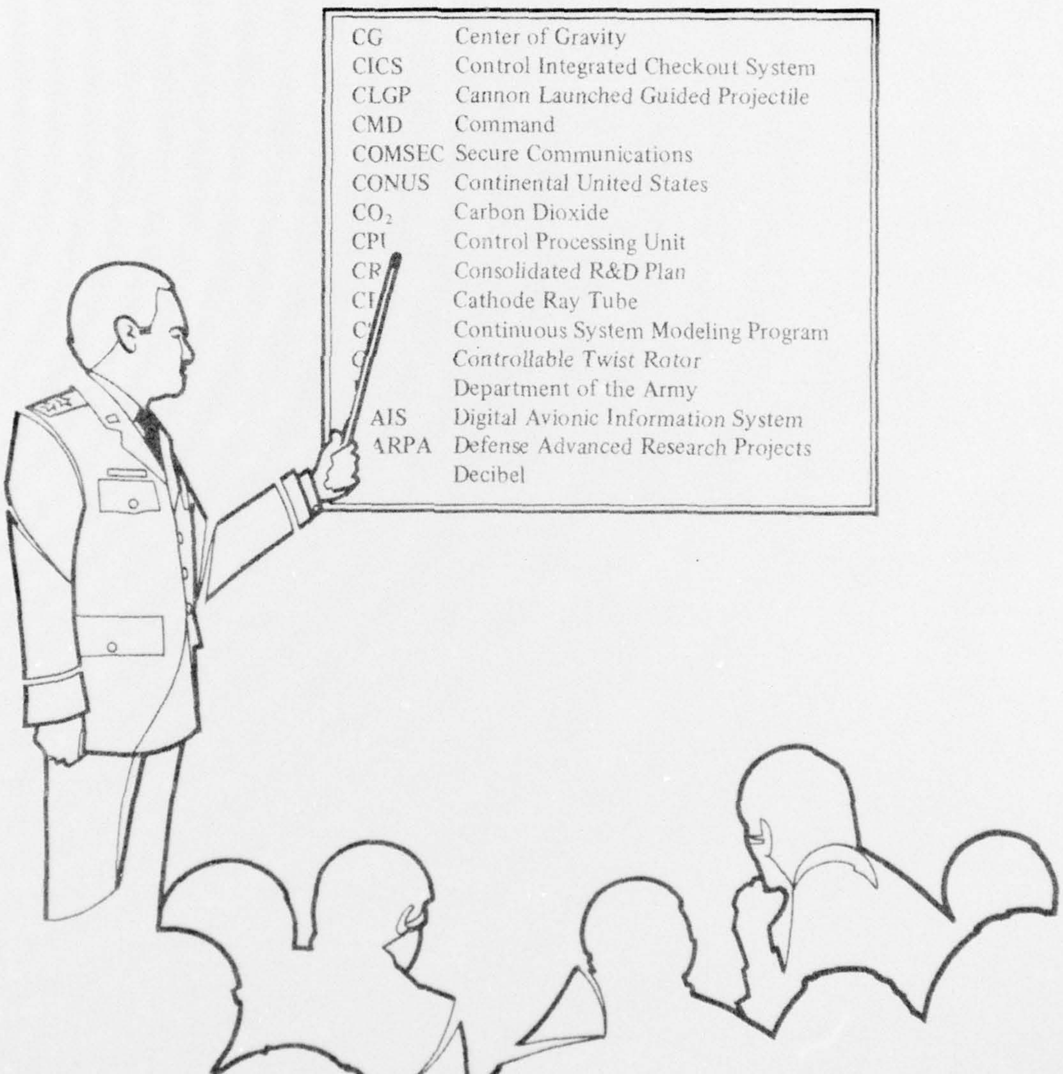


Figure RR–5. Distribution of required manpower by technology and PM offices.

ABBREVIATIONS / ACRONYMS



ABBREVIATIONS AND ACRONYMS

AACB	Aeronautics and Astronautics Coordinating Board
AAELSS	Active Arm External Load Stabilization System
AAH	Advanced Attack Helicopter
AAWS	Advanced Aerial Weapons System
ABC	Advancing Blade Concept
AC or ac	Alternating Current
A/C	Aircraft
ACT	Automatic Canon Technology
ADEN/DEFA	British/French 30mm Aircraft Cannon
ADF	Automatic Direction Finding
ADO	Advanced Development Objective
ADS	Aeronautical Design Standards
AEFA	(U.S. Army) Aviation Engineering Flight Activity
A&FC	Airworthiness and Flight Characteristics
AFB	Air Force Base
AFCS	Automatic Flight Control System
AFDP	Army Force Development Plan
AGARD	Advisory Group for Aerospace Research and Development
AGL	Above Ground Level
AIDAPS	Automatic Inspection Diagnostic and Prognostic System
ALT	Airborne Laser Tracker
AM	Amplitude Modulation
AMC	Army Materiel Command (now DARCOM)
AMCAWS	Advanced Medium Caliber Aircraft Weapon System
AMMRC	(U.S. Army) Army Materials and Mechanics Research Center
AMP	Amphere
AMPC	AMC Pamphlet
AMSAA	(U.S.) Army Materiel Systems Analysis Agency
AMST	Advanced Medium STOL Transport
AP	Armor Piercing
APE or APEval	Army Preliminary Evaluation
API	Armor-Piercing Incendiary
APPS	Analytical Photogrammetrical Position System
APU	Auxiliary Power Unit
AQP	Airworthiness Qualification Program
AQS	Airworthiness Qualification Specification
AR	Army Regulation
ARDPS	Army R&D Planning System
ARL	Aeromedical Research Laboratory
ARMS	Aircraft Reliability and Maintainability Simulation
ARO	Army Research Office
ARPA	Advanced Research Project Agency
ARRADCOM	(U.S. Army) Armament R&D Command
ARS	Aircraft Rocket Subsystem
ASARC	Army Systems Acquisition Review Council
ASCOD	Army System Coordinating Documents
ASE	Aircraft Survivability Equipment
ASH	Advanced Scout Helicopter
ASHOPS	Assault Support Helicopter Operations Simulation
ASOP	Army Strategic Objectives Plan
ASRO	Advanced Systems Research Office

ATAFCS	Airborne Target Acquisition and Fire Control System
ATC	Advanced Technology Components or Air Traffic Control
ATDE	Advanced Technology Demonstrator Engine
ATE	Advanced Technology Engine
ATMS	Air Traffic Management System
AVIM	Aviation Intermediate Support Maintenance
AVRADCOM	(U.S. Army) Aviation R&D Command
AVUM	Aviation Unit Maintenance
BED	Basic Engineering Development
BITE	Built In Test Equipment
BRL	Ballistics Research Laboratory
C^3	Command, Control, and Communications
CAD	Computer-Aided Design
CAD-E	Computer-Aided Design and Engineering
CAM	Computer-Aided Manufacturing
CARDS	Catalog of Approved Requirements Document
CBR	California Bearing Ratio
CCD/CID	Charge Coupled Device/Charge Injected Device
CDC	Combat Development Command or Control Data Corporation
CDEC	Combat Developments and Experimentation Command
CDR	Critical Design Review
CDS	Cleaning and De-icing System
CDU	Control Display Unit
CEP	Circular Error Probable
CG	Center of Gravity
CIP	Component Improvement Program
CLGP	Cannon Launched Guided Projectile
CMD	Command
COEA	Cost and Operational Effectiveness Analysis
COMSEC	Secure Communications
CONUS	Continental United States
CO_2	Carbon Dioxide
CPU	Control Processing Unit
CRDP	Consolidated R&D Plan
CRT	Cathode Ray Tube
CSTA	Combat Surveillance and Target Acquisition Laboratory
CTOL	Conventional Takeoff and Landing
CTR	Controllable Twist Rotor
CWS	Collision Warning System
DA	Department of the Army
DARCOM	(U.S. Army) Material Development and Readiness Command
DARPA	Defense Advanced Research Projects Agency
dB	Decibel
DC or dc	Direct Current
DCSRDA	Deputy Chief of Staff for Research, Development and Acquisition
D&E	Development and Engineering
DEPSECDEF	Deputy Secretary of Defense
DEVA	Design Evaluation Analysis
D&F	Determination & Finding
DGW	Design Gross Weight

DIMAP	Digital Modular Avionics Program
DIMODE	Discontinuity Modulation Effect
DME	Distance Measuring Equipment
DN	Diameter (mm) Times RPM
DOC	Direct Operating Cost
DP	Development Plan
DPROC	Draft Preliminary ROC
DS	Direct Support (now Intermediate Support Level)
DSARC	Defense Systems Acquisition Review Council
DOD	Department of Defense
DOT	Department of Transportation
DT	Development Test
DTB	Detection Time Variation
DTUPC	Design to Unit Production Cost
ECCM	Electronic Counter Countermeasures
ECM	Electronic Countermeasures or Electrochemical Machining
ECOM	(U.S. Army) Electronics Command
EDM	Electrical Discharge Machining
EDT	Engineering Development Test
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
ERP	Effective Radiating Power
ET	Engineering Test
EVADE	Evaluation of Air Defense Effectiveness
EW	Electronic Warfare
EWL	Electronic Warfare Laboratory
F	Fahrenheit
FAA	Federal Aviation Administration
FARRP	Forward Area Rearm/Refuel Point
FBW	Fly-By-Wire
FCC	Flight Coordination Center
FDS	Flight Director System
FEBA	Forward Edge of Battle Area
FFAR	Folding Fin Aerial Rocket
FFH	Fast Frequency Hopping
FLIR	Forward Looking Infrared
FM	Frequency Modulation
FOC	Flight Operations Center
FOD	Foreign Object Damage
FORSCOM	(U.S. Army) Forces Command
FORTRAN	Formula Translation
FPM	Feet Per Minute
FT or ft	Feet
FY	Fiscal Year
FYDP	Five Year Defense Plan
G or g	Gravity
GCA	Ground Controlled Approach
GCS	Ground Control Station
GCT	Government Computation Test
GE	General Electric Company

GFP	Government Furnished Property
GHz	Gigahertz
GLAS	Gust and Load Alleviation System
GLLD	Ground Laser Locator Designator
GPM	Gallons Per Minute
GPS	Global Positioning System
GPU	Ground Power Unit
GRMS	Generalized Rotor Model System
GS	General Support (now Intermediate Support Level)
GSE	Ground Support Equipment
GTV	Ground Test Vehicle
HE	High Explosive or Human Engineering
HEAT	High Explosive Anti-Tank
HEDP	High Explosive Dual Purpose
HEI	High Explosive Incendiary
HEL	Human Engineering Laboratory
HELLFIRE	Helicopter Launched Fire and Forget Antitank Missile System
HERF	High Energy Rate Forming
HF	High Frequency or Human Factors
HGMS	Helicopter Ground Mobility System
HLH	Heavy Lift Helicopter
HMD	Helmet Mounted Display
HMMS	HELLFIRE Modular Missile System
HOGE	Hover-Out-Of-Ground-Effect
HP or hp	Horsepower
HQ	Headquarters
HR or hr	Hour
HRU	Heading Reference Unit
HUD	Head-up Display
Hz	Hertz
I^2	Image Intensifiers
IACS	Integrated Avionics Control System
IBM	International Business Machines Corporation
ICAO	International Civil Aviation Organization
ICNI	Integrated Communication, Navigation, Identification
ICNS	Integrated Communication and Navigation System
IFF	Identification, Friend or Foe
IFR	Instrument Flight Rules
ILLIAC IV	Fourth Generation Computer with Sixty-Four Slave Processors Working on Master/Slave Concept
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IMLS	Interim Microwave Landing System
I/O	Input/Output
IOC	Initial Operational Capability
IPR	In Process Review
IPT	Initial Production Testing
IR	Infrared
IRCM	Infrared Countermeasures
IR&D	Independent Research and Development
ISM	Intermediate Support Maintenance

ISO	International Standards Organization
ITAV	Individual Tactical Aerial Vehicle
JCS	Joint Chiefs of Staff
JCTG	Joint Commander's Technical Group
JPO	Joint Program Office
JTIDS	Joint Tactical Integrated Data System
KN or kn	Knot
KE	Kinetic Energy
KM or km	Kilometer
KVA or KW	Kilowatt
KTAS	Knots-True Air Speed
LA	Low Altitude
LAH	Light Attack Helicopter
LANS	LORAN Airborne Navigation Subsystem
LB or lb	Pound
LCC	Life Cycle Cost
LCMM	Life Cycle Management Model
L/D	Lift/Drag
LINS	Laser Inertial Navigation System
LLLTV or LLTV	Low-Light-Level TV
LLNO	Low Level Night Operations
LOA	Letter of Agreement
LOH	Light Observation Helicopter
LORAN	Long-Range Navigation
LOS	Line-of-Sight
LOTAWS	Laser Obstacle/Terrain Avoidance Warning System
LOTS	Logistics Over-The-Shore
LP	Limited Production
L&R	Launch and Recovery
LRIP	Limited Rate-Initial Production
LSI	Large Scale Integration
LTD	Laser Target Designator
LUH	Light Utility Helicopter
LWL	Lightweight Launcher
LZ	Landing Zone
MACI	Military Adaptation of Commercial Items
MAGIIC	Mobile Army Ground Imaging Interpretation Center
MARS	Mid-Air Recovery System
MAT	Maturity
MBO	Mean Time Between Overhaul
MERADCOM	(U.S. Army) Mobility Equipment Research and Development Command
MHD	Magnetohydrodynamics
MIRADCOM	(U.S. Army) Missile R&D Command
MLH	Medium Lift Helicopter
MLS	Microwave Landing System
MM or mm	Millimeter
MMH/FH	Maintenance Manhours per Flight Hour
MMT	Manufacturing Methods and Technology
MN	Materiel Need

MQT	Material Qualification Test
MRP	Military Rated Power
MSL	Mean Sea Level
MT	Manufacturing Technology
MTBF	Mean Time Between Failures
MTBR	Mean Time Between Removal
MTBUM	Mean Time Between Unscheduled Maintenance
MTI	Moving Target Indicator or Mechanical Technology
MTTR	Mean Time to Repair
μm	Micron
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structure Analysis
NATO	North Atlantic Treaty Organization
NAV	Navigation
NC/CAM	Numerical Control/Computer-Aided Manufacturing
NM	Nautical Mile
NMLS	National Microwave Landing System
NOE	Nap of the Earth
NRP	Normal Rated Power
NVL	Night Vision Laboratory
OCCM	Operation Counter-Countermeasure
OCRD	Office, Chief of Research and Development
ODDR&E	Office of the Director of Defense Research and Engineering
OGE	Out-Of-Ground-Effect
O&O	Organizational And Operational
OPR	Objectives, Priority and Rationale
OSD	Office, Secretary of Defense
OT	Operational Test
OTAS	Observation Target Acquisition System
PADS	Piloted Aircraft Data Systems
PANS	Position and Navigation System
PDR	Preliminary Design Review
PEM	Production Engineering Measures
PEMA	Procurement of Equipment and Missiles, Army
PEP	Producibility Engineering and Planning
PFAT	Preliminary Flight Approval Test
PI	Product Improvement
PIDD	Prime Item Description Document
PIP	Product Improvement Program
PLRS	Position Location Reporting System
PM	Project Manager
PMD	Panel Mounted Display
PNVS	Pilot Night Vision System
POL	Petroleum, Oil and Lubricants
POM	Program Objectives and Memorandum
PRIMERS	Project Improvement Management Information Reports
PSDE	Preliminary Systems Design Engineering
PSF or psf	Pounds per Square Foot
PSG/MFD	Programmable Symbol Generator and Multifunction Display
PSI or psi	Pounds per Square Inch
PWD	Proximity Warning Device

QMDO	Qualitative Materiel Development Objective
QMR	Qualitative Materiel Requirement
RAGS	Research Aircraft Ground Station
RAM	Reliability, Availability, and Maintainability
RAM/D	Reliability, Availability, Maintainability, Dependability
RC	Radio Control
RCS	Radar Cross Section
R&D	Research and Development
RDE	Research, Development and Engineering
RDT&E	Research, Development, Test and Engineering
RF	Radio or Radar Frequency
RFP	Request for Proposal
R&M	Reliability and Maintainability
RMI/HSI	Radio Magnetic Indicator/Horizontal Situation Indicator
RMS or rms	Root Mean Square
ROC	Required Operational Capability
RPAODS	Remotely Piloted Aerial Observation/Designation System
RPM or rpm	Revolution Per Minute
RPV	Remotely Piloted Vehicle
RR	Resources Required
RSRA	Rotor Systems Research Aircraft
RSTA/D	Reconnaissance, Surveillance, Target Acquisition and Designation
RTCOD	Research and Technology Coordinating Document
RVR	Runway Visual Range
SAG	Study Advisory Group
SAM	Surface to Air
SAS	Stability Augmentation System
SCAS	Stability and Control Augmentation System
SCSC	Shallow Cone Shaped Charge
SEANITEOPS	Southeast Asia Night Operations
SEC or sec	Second
SFC	Specific Fuel Consumption
SHP	Shaft Horsepower
SIF	Selectable Identification Feature
SINCGARS	Single Channel Ground and Airborne Radio System
SLAE	Standard Lightweight Avionics Equipment
SLAR	Side-Looking Airborne Radar
SLS	Sea-Level Standard
SNAPAC	Stearable Null Antenna Processor for Airborne Communications
SOFTAR	Stand-Off Fixed Target Detection Radar
SOTAS	Stand-Off Target Acquisition System
SSB	Single Sideband
ST	Service Test
STA	Static Test Article
STD	System Technology Demonstrator
STAGG	Small Turbine Advanced Gas Generator
STOG-78	Science and Technology Objective Guide, FY78 (CONFIDENTIAL)
STOL	Short Takeoff and Landing
SUR/VTOL	Surveillance/Vertical Takeoff and Landing Aircraft System
TACAN	Tactical Air Navigation
TADS	Target Acquisition and Designation System

TAGS	Tactical Aircraft Guidance System
TAMMS	The Army Maintenance Management System
TASS	Tactical Avionic System Simulator
TA/TF	Terrain Avoidance/Terrain Following
TBO	Time Between Overhaul
TBR	Time Between Removal
TCATA	TRADOC Combined Arms Test Activity
TCP	Technical Coordinating Papers
TDMA	Time Digital Multiple Access
TIIF	Tactical Imagery Interpretation Facility
TIPL	Tactical Imagery Processing Laboratory
TISAL	Tactical Instrument Steep Approach and Landing
TLL	Tactical Low-Level
TLS	Tactical Landing System
TOW	Tube Launched, Optically Tracked, Wire Guided
TP	Target Practice
TRADOC	(U.S. Army) Training and Doctrine Command
TROSCOM	(U.S. Army) Troop Support Command
TTCP	The Technical Cooperation Panel
TV	Television
UA	Up and Away
UACL	United Aircraft of Canada, Limited
UFIR	Universal Far Infrared
UHF	Ultra High Frequency
USAAEFA	U.S. Army Aviation Engineering Flight Activity
USAARL	U.S. Army Aeromedical Research Laboratory
USAARRADCOM	U.S. Army Armament R&D Command
USAAVRADCOM	U.S. Army Aviation R&D Command
USACDC	U.S. Army Combat Developments Command
USACDEC	U.S. Army Combat Developments and Experimentation Command
USADARCOM	U.S. Army Materiel Development and Readiness Command
USAECOM	U.S. Army Electronics Command
USAF	U.S. Air Force
USAFORSCOM	U.S. Army Forces Command
USAMERADCOM	U.S. Army Mobility Equipment Research and Development Command
USAMIRADCOM	U.S. Army Missile R&D Command
USAMMRC	U.S. Army Materials and Mechanics Research Center
USAREUR	U.S. Army, Europe
USARTL	U.S. Army Research and Technology Laboratories
USATRADOC	U.S. Army Training and Doctrine Command
USATSARCOM	U.S. Army Troop Support and Aviation Material Readiness Command
USMC	U.S. Marine Corps
USN	U.S. Navy
UTM	Universal Transverse Mercator
UTS	Ultimate Tensile Strength
UTTAS	Utility Tactical Transport Aircraft System (Black Hawk)
V	Vertical or Air Speed
VALT	VTOL Approach and Landing Technology
VAT	Vulnerability Analysis Team
VE	Value Engineering
VHF	Very High Frequency
VIM/VAR	Vacuum Induction Melt/Vacuum Arc Remelt

VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional Range
VR	Vulnerability Reduction
VROC	Vertical Rate of Climb
V/STOLAND	V/STOL Advanced Autopilot System
VTOL	Vertical Takeoff and Landing
WSM(O)	Weapons Systems Manager (Office)
WOT	Weight On Target
WOWS	Wire Obstacle Warning System
WP	White Phosphorous
WT or wt	Weight

GPO 793–403